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SEABED MINING

REPORT TO OFFICE OF TECHNOLOGY ASSESSMENT, U.S. CONGRESS

(Contract No. 433-3920.0)

by

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SEABED MINING

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This paper reports briefly on three aspects of seabed minerals deposits as possible sources of future cobalt and/or manganese supplies: 1) current and prospective industrial activity of firms engaged in preparation for exploitation of seabed manganese nodule deposits; 2) the activities of foreign governments in efforts to exploit seabed nodules; and 3) the current economic status of oceanic cobalt-bearing ferromanganese crusts. Background for the report comes from a continuing three-year study by the contractor of the factors shaping development of the international marine mining industry. Much of the information in this report has either been derived from or confirmed by an extensive series of interviews with responsible officials from seabed mining organizations and their parent companies, both domestic and foreign. Exhibit 1 shows the major topics addressed in those interviews.

1. ACTIVITIES OF SEABED MINING FIRMS

Companies, States, and Parties in Interest: Organizational Relationships and Motivations

A number of large international companies, as well as several national governments, have invested a total of several hundred million dollars over the last decade in efforts to develop a capability to find and recover metal-rich manganese nodules on the ocean floor. Until about 1980, these investments were directed mainly toward technological R&D and exploration. Now virtually all that spending has stopped. Several major companies have either withdrawn altogether or have declined to make further expenditures. Achievement of an international consensus on the legal regime established by the LOS has been held up primarily by objections from the United States and certain other industrial nations to the seabed mining provisions of the treaty. It is somewhat ironic that, at the same time, economic prospects for seabed mining seem to be crumbling.

Different types of actors are involved in efforts to develop the capability to mine and exploit metals in seabed manganese nodules. These are:

(1) seabed mining enterprises, including
   (a) private companies and commercial organizations, such as the major international seabed mining consortia, and
   (b) state enterprises, organs of national governments directly investing in exploration and development similar to consortia efforts; and
(2) the national governments themselves.

Companies act as private enterprise, seeking to serve their own commercial interests whatever the official foreign policies of their home nations. The national govenments are best seen as independent from the seabed mining organizations within their jurisdiction; although they in fact have varying degrees of participation in and control over the ownership and management of those organizations. National governments act to further their own broader interests, at the same time tending to respond to the needs and urgings of commercial enterprises operating under their jurisdiction. In some cases, a national government is the seabed mining enterprise. In other cases, a national government is an active participant or leading member of a commercial group. National governments have sometimes been interested parties that have provided various forms of financial support to a commercial enterprise without participating in its management.

Recent Activities in Area Entitlement Conflict Resolution

If and when deep seabed mining takes place, whether under the legal authority described by the United Nations Law of the Sea Convention (LOS) or some alternative multilateral understanding, certain tangible advantages will accrue to nations or organizations that have qualified as "pioneer investors" or "pre-enactment explorers" and that have obtained entitlements to exclusivity of exploration and exploitation activity within areas of the seabed. With few exceptions, the only major activity taking place within the seabed mining consortia appears to be directed toward legal and regulatory ends, and, more specifically, toward the acquisition of assured access to preferred prospective mining sites in the seabed.

The involvement of seabed mining enterprises in conflict resolution activities is summarized in Exhibit 2. Two "tracks" toward the establishment of legal rules governing seabed mining have evolved because several prospective seabed mining states have declined to become party to the Law of the Sea Convention (LOS). Development of legal assurances of security to work within a claimed area has thus proceeded along two different tracks: (1) the LOS track; and (2) a prospectively complementary, but currently separate and potentially competing track, based on domestic laws, multilateral arrangements for reciprocal recognition of entitlements under those domestic laws, and private agreements to facilitate such reciprocation. West Germany, the United Kingdom, France, Japan, and the Soviet Union have enacted their own domestic seabed mining laws. As a precursor to a more comprehensive reciprocating states agreement (RSA), France, West Germany, the United Kingdom, and the United States have signed an "Agreement Concerning Interim Arrangements Relating to Polymetallic Nodules of the Deep Sea Bed" (Interim Agreement) of September 2, 1982 (Interim Agreement, 21 I.L.M. 950, 1982).

Industry Negotiations. Six seabed mining consortia, which include private and public companies from the United States, Canada, the United Kingdom, West Germany, Japan, Belgium, the Netherlands, Italy, and France, have signed an "Industry Arbitration Agreement" to resolve exploration area overlaps. The consortia involved in these private negotiations are OMA, OMCO, KCON, OMI, AFERNOD, and DORD (these groups are described below). The agreement and associated negotiations are subject to a secrecy agreement and have been kept

extremely confidential. Although there has been no public announcement that overlaps have been resolved, several industry sources have indicated privately that a resolution has been reached on the basis of "equal sharing." In any event, the industry agreement cannot effect worldwide conflict resolution since state enterprises, most notably from the Soviet Union, India, and South Korea, have not been involved.

Seabed Mining Enterprises

A striking feature of the embryonic seabed mining economy is the mixed-form character of the groups assembled to develop and conduct the activity. None of the seabed mining enterprises is composed exclusively of privately owned companies. All have at least some participation by national governments or state companies, and some are largely or entirely governmental operations. The organization, activities, and current status of the major corporate interests interests in seabed mining are summarized in Exhibit 3.

Commercial Consortia

OMA

An early commercial pioneer in seabed mining research and exploration is the Ocean Mining Associates (OMA) consortium. This U.S. partnership was formed in 1974. That same year, OMA's operating company, Deepsea Ventures Inc., attempted to file a claim with the U.S. State Department for a 60,000 square kilometer area of the Pacific. In recent years, OMA has been the most active of the commercial consortia, thanks largely to an infusion of funds brought to the group when it was joined in late 1980 by ENI, the Italian national oil company. Like most governmental efforts in this area, the Italian efforts appear to be motivated primarily by an extra-economic interest in long-run diversity of supply rather than the profit potential of seabed metals sales. In addition to ENI's less-than-quarter share, the consortium is held equally in greater-than-quarter shares by: Sun, a diversified U.S. energy company; U.S. Steel, the largest U.S. steel producer and a major consumer of manganese; and Union Miniere, a Belgian mining concern, associated with Belgian's large Societe Generale, which holds a major position in the world cobalt market. The consortium's total expenditures have been estimated as over $130 million. As seen in Exhibit 4, OMA holds about 21% of issued seabed mining patents. Most recently, however, its activities have been concentrated on transferring information to the Italian partner and on securing site claims and licenses. Significantly, none of the OMA partners comes from a nation that is party to the LOS Convention. Therefore, OMA is ineligible to qualify as a pioneer explorer under the LOS PIP requirements.

OMCO

The commercial group that comes closest to being a purely private enterprise is the Ocean Minerals Company (OMCO), also known as the "Lockheed Group." This United States partnership consists of four companies from only two nations, the United States and The Netherlands. Organized by Lockheed in 1977 as an outlet for its high-technology deepsea operation capabilities, the

OMCO consortium also includes AMOCO Ocean Minerals Company, a wholly owned subsidiary of Standard Oil of Indiana holding about 31%, Royal Bos Kalis, a Dutch marine engineering concern with less than 8%, and Billiton International Metals, a Dutch subsidiary of Royal Dutch Shell with about 31%.

As operator and prime contractor for the OMCO partnership, Lockheed is in the unique position of earning immediate revenues from the group's activities, though these activities represent direct outlays for the group's other partners. Some significant portion of Lockheed's share in the venture was, furthermore, based on "in-kind" contribution of intangible capital acquired through earlier company efforts on seabed mining techniques, in part through the company's involvement in the Hughes' Glomar Explorer submarine recovery operation.

Expenditures by the group, largely on development of a sophisticated remote-controlled mobile miner, are estimated at more than $120 million. In part because of a decision to patent an entire recovery system rather than individual components, OMCO holds only 7% of seabed mining patents (see Exhibit 4). In part because the Netherlands is a party to the LOS Convention, while the United States has withdrawn, and in part because of the souring economics of seabed mining, Billiton has announced its withdrawal from OMCO, though legal implementation of this withdrawal appears to be still under way. Similarly, Bos Kalis has declined to contribute to OMCO activities since early 1981, preferring instead to let its share dilute. The position to be taken by AMOCO toward further activities in the group has yet to be seen, but Lockheed continues to promote additional investment in marine mining.

KCON

The Kennecott Consortium (KCON), was formed as an unincorporated joint venture at the initiative of the Kennecott Copper Corporation in 1974. It is composed of: Kennecott (40%), a wholly-owned subsidiary of Standard Oil of Ohio (SOHIO), which in turn is controlled by British Petroleum (BP); BP itself, with 12%; the British mining houses RTZ (12%) and Consolidated Gold Fields (12%); the Canadian mining company, Noranda (12%); and Mitsubishi (12%) the Japanese conglomerate.

The consortium's ownership structure in recent years has become dominated increasingly by British interests. The original members were Kennecott (50%), at that time an independent U.S. copper corporation, RTZ (20%), Consolidated Gold Fields (10%), Noranda (10%), and Mitsubishi (10%). Formation of the group and participation in it by British companies were aided in 1974 when the British government made a loan to RTZ and Consolidated Gold Fields of £ 830,000 under the Science and Technology Act of 1965. In 1977, British Petroleum was brought into the consortium through the purchase of half RTZ's share and assumption of half of RTZ's government loan responsibility. Throughout most of the postwar period, the British government has held about 50% interest in BP, with reserved seats on the Board of Directors. More recently, however, the government share in BP has fallen to about 40%. BP acquired effective control over Kennecott when Standard Oil of Ohio (SOHIO), already controlled by BP, bought Kennecott in 1981. Subsequent readjustment

in consortium shares reduced Kennecott's position to 40% and increased each of the other members' shares to 12%. The consortium was managed by Kennecott, but decisions on expenditures and program of work were made by a full committee of members (House of Commons, 1981). If Kennecott's 40% share is included as a British holding, rather than U.S., the combined British share in the group is 76%. The remaining 24% is split between the companies from Canada and Japan, who, unlike the British, are parties to the LOS Convention.

It appears that all the Kennecott Group's members were motivated primarily by the prospect of eventual seabed mining profits, rather than, as may have been the case in the Lockheed Group, by more immediate revenues from the sale of R&D services. As managing company for the group, however, Kennecott did earn such revenues, apparently billing the consortium for its services at cost (House of Commons, 1981). In any event, most of the roughly $50 million estimated to have been spent by the group was invested before 1976, when the group became virtually inactive in exploration and technical development. The KCON group holds 18% of issued seabed mining patents, most of which are concentrated in the metals processing area (see Exhibit 4).

OMI

The multinational development consortium, Ocean Management Inc. (OMI), was organized in 1975 by INCO (formerly International Nickel Company of Canada), which has been for many years the dominant factor in the international nickel market. INCO was a pioneer in studies of the economic potential of seabed manganese nodules having begun work in the late 1960s. INCO's involvement was initiated not out of sincere belief that nodules could be commercially exploited but rather to protect its market position against the possibility of seabed competition (INCO, Annual Report, 1968).

OMI is a U.S. partnership governed by a partnership committee with an annually-rotating chairmanship and managed on contract by a jointly-held U.S. corporation. In addition to the Canadian INCO (25%), it is composed of: SEDCO (25%), a U.S. marine operator; Deep Ocean Minerals Company or DOMCO (25%), a complex Japanese corporate joint venture of 24 companies led by the Sumitomo Corporation; and Arbeitsgemeinschaft Gewinnbare Rohstoffe (AMR) (25%), a West German partnership shared by Metallgesellschaft, the largest nonferrous metals company in Germany, Preussag, a major German extractive resources company with extensive marine operations capabilities, and Salzgitter, a state-owned diversified steel company with interests in shipbuilding and marine operations. AMR was formed in 1974 with the active encouragement of the West German government, including 50-100% governmental funding for AMR efforts on a project-by-project basis and loans and grants from the FRG Ministry of Research and Technology (Fellerer, 1978). Activities of the Japanese group in OMI have also been supported by loans from the Japanese government.

OMI is one of only two consortia that have successfully realized their technological concepts through the recovery of large amounts of nodules, this in 1978. OMI holds 12% of all seabed mining patents surveyed in Exhibit 4, about equally divided between recovery and metallurgical processing. Altogether, OMI is estimated to have spent $50-100 million on ocean mining R&D

and exploration, practically all before 1980 when site-specific exploration activities were concluded. The consortium's only current activities are its efforts to secure exploration area claims.

OMI appears to be subject to a great deal of internal stress because of a diversity of motivations and objectives among its partners. The German and Japanese groups seem responsive to the interests of their governmental sponsors in developing alternative sources of long-run materials supply. INCO, on the other hand, may be primarily interested in protecting its eroding position in the world nickel market, while SEDCO was drawn into the venture as much to diversify future demand for its marine technology capabilities as to earn profits directly from metals production and marketing. This consortium's decision making is sometimes frustrated by its "rule of unanimity," which confers an effective veto on each partner. Diplomatically, the group has been split in half, with Canada and Japan both parties to the LOS Convention and treaty process, while the United States and West Germany have declined to join the treaty.

FRANCE (Afernod and Gemonod)

The French effort in seabed mining is almost entirely governmental, although two private companies have been involved in the French consortium. The Association Francaise pour l'Etude et la Recherche des Nodules (AFERNOD) is a French syndicate formed in 1974. Its major partner and leading organization is the French national agency for development and exploitation of ocean resources, IFREMER (formerly Centre National pour l'Exploitation des Oceans or CNEXO) which accounts for about 70%. The next major partner is also an agency of the French government, the extensive Commissariat a l'Energie Atomique (CEA) which holds about 20% interest in the group (Balligand et al., 1979). Both private partners -- Societe Metallurgique le Nickel (SLN), the major French nickel producer, and Chantiers du Nord et de la Mediterranee (formerly Chantiers de France-Dunkerque of the Empain Schneider conglomerate), a large shipbuilding concern -- have played relatively minor roles, each accounting for about 5% of the total. The group is estimated to have spent a total of nearly $50 million through 1981, distributed as follows: exploration 50%; mining 34%; processing 14%; and management 2%. Although there has been little development or exploration activity since 1979, the French govenment is reported to have budgeted $17 million for AFERNOD in 1982 (GAO, 1983).

In recent months a new, solely-governmental group consisting of IFREMER and CEA has been formed to continue R&D work. This new group is a "Groupement d'Intérêt Public" (GIP) and is called GEMONOD. AFERNOD will continue to exist formally, but its activities will be limited to the acquisition of exploration and mine site licenses. Some well informed French sources assert that the true objective is to push the remote shuttle collector system to a point where development can be terminated without embarrassment.

France has signed the LOS Convention and qualifies as a pioneer investor under PIP. The French are also party to the Interim Agreement. France takes a long-term strategic view of the value of a seabed mining stake. Unlike the Japanese, France has no involvement in international or multinational commercial seabed mining enterprises.

JAPAN

Although a number of Japanese companies, most notably Mitsubishi and Sumitomo, are involved actively in international commercial seabed mining consortia, the Japanese government also sponsors a large domestic consortium. In fact the Japanese government appears consciously to have pursued a "dual policy" for seabed mining, combining on the one hand coordination of an exclusively national program with encouragement of Japanese company participation in the international consortia on the other hand. Within the national program, there is a complex and intimate relation between the government and participating private companies that sometimes blurs the distinction between the two. All Japanese companies that are members of international consortia also are participants in the national program.

The national effort is now focused through a joint government-industry firm, Deep Ocean Resources Co., Ltd. (DORD) formed in 1982 to promote nodule exploration and mining. DORD is 80% financed by the government and 20% by some 50 private companies, including the nearly 40 members of Deep Ocean Minerals Association (DOMA). Prior to the formation of DORD, DOMA was the primary organ linking Japanese national and private seabed mining exploration and development efforts, having been established as a technical promotion group in 1974 under the sponsorship of the Ministry of International Trade and Industry (MITI). Development of a manganese nodule mining system has been designated since 1981 as one of eight national "Large Scale Projects," with a projected 1981-1989 budget of around $86 million (Japan, 1982).

Japan is motivated by the prospects of diversified materials supply offered by seabed mining development. Japan has signed the LOS Convention, and is participating in PrepCom, and the Japanese are not a party to the Interim Agreement (21 I.L.M. 808-814, 1982). The Japanese have been involved in conflict resolution discussions associated with the Interim Agreement and the private companies' Arbitration Agreement. One of the expressed purposes for the formation of DORD was for it to act as a delegate from Japan in international discussions for the division of prospective seabed mining areas.

State Enterprises

In addition to the major commercial efforts, there are also several solely governmental R&D programs. Most of these are relatively new and have not been mounted on the same financial scale as the commercial consortia. In each case, these governmental programs appear to be motivated more by interest in alternative sources of long-run materials supply than by prospects for commercially generated profits from the production and sale of metals.

USSR. Perhaps the most aggressive of the exclusively governmental seabed mining pioneers is the Soviet Union. Little is publically known in the West about the nature of the Soviet seabed mining program. Scientific exploration for seabed nodules was underway by the Soviets as early as the early 1960s, most notably with the research vessel Vitjaz (Bezrukov, 1970). Since 1977,

Soviet agencies have been prospecting in various areas, including the Clarion-Clipperton zone of the Pacific where the commercial consortia efforts have been concentrated, and have been developing exploration and recovery technology (United Nations, 1982). As early as 1974, in fact, the Soviets were prospecting with a specialized ship, the Illmenit (Linebaugh, 1982). The Soviets enacted a domestic seabed mining law, similar to the U.S. law, on April 17, 1982 (21 I.L.M. 551-553, 1982). The Soviets are a party to the LOS Convention and have been actively involved in the PrepCom proceedings. They have established that there is no area claim conflict with India.

INDIA. India appears to be the first developing nation to carry out a successful oceanographic program dedicated to manganese nodule exploration (United Nations, 1982). Nodules are known to exist in the central Indian Ocean (Cronan and Moorby, 1982), and the Indians are focusing their prospecting program on that area. The Indian Council of Scientific and Industrial Research and other agencies have also given high priority to the development of technology for nodule mining, recovery, and beneficiation under a program called the "All India Coordinated Project" supervised by the government's Department of Ocean Development (United Nations, 1982). In addition to the cost of ships, India reports that it has invested "several million" dollars in exploration and resource assessment in the Indian Ocean. The Indian government has signed the LOS Convention. India has not been involved in the Interim Agreement or associated discussions and has played an active role in the LOS PrepCom proceedings. India's area claim has not been publicly announced, but the Indians have stated that their interest is in the Indian Ocean only and that they are not in conflict with the Soviet Union's claim.

SOUTH KOREA. South Korea has launched a national program for seabed mining exploration and development, announcing that it will have invested $30 million by the end of next year. Little is publicly known about the Korean effort, except that it appears to be under the supervision of the Korean Ocean Research and Development Institute. The extent to which it will be organized as a state operation, as private enterprise, or as mixed-form remains to be seen. South Korea adopted LOS and has been participating in the PrepCom proceedings.

CHINA. China has conducted a manganese nodule R&D program since 1976, and successfully recovered nodules in 1978 and 1979 (United Nations, 1982). Chinese exploration has taken place in various areas of the Pacific, including an "area of the central Pacific near the Equator." The total investment made in these activities by the Chinese government has been reported as over 80 million yuan (Renminbi), of which over 16 million yuan was devoted directly to surveying activity. China is a party to the LOS Convention and participates in PrepCom. The Chinese have in no way been associated with the Interim Agreement. The Chinese have not yet sought claim to a seabed exploration and mine site, but they have described exploration and development activities and may be presumed to have interest in qualifying for a site under the PIP provisions of the LOS.

2. ACTIVITIES OF FOREIGN GOVERNMENTS IN PACIFIC NODULES

Basic Approaches to Government Involvement in Seabed Mining

There are a variety of methods through which national governments involve themselves in the development of capabilities to recover and exploit deep seabed manganese nodules. There are also different degrees of commitment to seabed mining activities and different motivations for governmental support. Probably the most actively involved governments have been France, Japan, and West Germany (FRG). The French effort has been made almost entirely through direct government expenditures, with only limited investments by two private companies. Seabed mining development in FRG has been underwritten to the tune of 50-70%, about 90% of that in the form of direct research grants and about 10% through attractive exploration loans. The Japanese effort has been a mix of government initiative and support with private investment and execution. A major portion of the Japanese program, consisting of both participation of Japanese companies in international consortia and an all-Japanese commercial development program, is funded by the Ministry of International Trade and Industry (MITI) through both direct outlays and loans. The basic degree of commitment, means of involvement and motivation of national governments in seabed mining are summarized here. Involvement of national governments in international efforts to establish clear legal procedures for seabed mining are summarized in Exhibit 5.

JAPAN

Of all national governments with an involvement in seabed mining, the Japanese appear at this time to be the most committed. In fact, the government provides the great bulk of financial support for a new all-Japanese commercial consortium and the development of a commercially feasible recovery system one of the nation's select "Large Projects." The Japanese interest appears to be motivated mainly by a desire to cultivate a diversity of longrun supply sources for the contained metals.

In Japan, the boundary between government and private enterprise is blurred, so it is sometimes difficult accurately to characterize some activity as either private or government. There may be a much greater and more direct alignment between public goals and industrial effort in Japan than in the United States. Because interaction between private enterprise and government is more formally institutionalized there, companies have an immediate influence and a major voice in the articulation of national objectives. At the same time, they are more organically integrated into development programs. The structure of governmental involvement in seabed mining development is represented in Exhibit 6.

Japanese seabed mining objectives are expressed primarily through the Ministry of International Trade and Industry (MITI). They are defined and executed, however, through a complex network of interrelated agencies, public associations, corporate organizations and private companies. A dual policy has been pursued in which some companies have been encouraged to participate

in private international commercial consortia while at the same time joining with other Japanese companies to develop an independent national commercial capability. Participation in the international consortia has been supported mainly through the award of low-interest, fixed rate loans repayable on generous terms. Support has also been rendered through the establishment of research programs and information exchange at semi-governmental research facilities and through public association. Efforts toward the creation of Japanese national seabed mining capability have been supported more directly by government subsidy.

Mitsubishi holds 12% share in KCON, and the Sumitomo-led DOMCO group holds 25% of OMI. In addition, the domestic Japanese effort coordinated through a joint government-industry firm, Deep Ocean Resources Co., Ltd. (DORD) formed in 1982 to promote nodule exploration and mining, has moved ahead with an ambitious investment program. DORD is a Japanese corporation formed by 49 Japanese companies with the prior assistance of the Japanese government. DORD is financed largely by the government with some contribution by the private companies, including the nearly 40 members of Deep Ocean Minerals Association (DOMA). Prior to the formation of DORD, DOMA was the primary organ linking Japanese national and private seabed mining exploration and development efforts, having been established as a technical promotion group in 1974 under the sponsorship of MITI. DOMA was organized as a publicly authorized association with an initial capital budget of Y500-million, half of which came from MITI (Chilton, 1977). The members of DOMA include MITI and some 35 private companies engaged in the businesses of: general trading, mining, shipbuilding, steelmaking, shipping, electric appliances, and fishing. Ten DOMA companies are also members of international consortia. An official from Sumitomo Metal Mining became DOMA's first chairman. DOMA was formed to engage in R&D but not to exploit nodules on a commercial level. DOMA provided a forum for discussion on the formation of a commercial mining entity. DOMA's major activities have been: 1) study and research of deep ocean minerals; 2) planning and promotion of coordinated projects; 3) publicity to support maintenance of momentum; and 4) cooperation in the execution and administration of policies for seabed minerals development.

From 1975 through 1979, DOMA chartered the Hakurei Maru to conduct seabed surveys south of Hawaii. By 1977, Japanese exploration technology had advanced to the point where the government ordered the construction of the Hakurei Maru II, a geological survey ship designed specifically to explore for manganese nodules. This research vessel was equipped with high-speed underwater television developed by DOMA to photograph the seabed, an automatic nodule densitometer to translate the photographic data into nodule density data, sonar, telemetry, an underwater illumination system, and a towing system. The Hakurei Maru II was completed in 1980 by Shimonoseki Shipyards, a subsidiary of Mitsubishi Heavy Industries.

The Japanese government has received over 160 patent applications, many from inventors outside the country. Only 37 seabed mining patents have issued, and of these, 27 are held by Japanese inventors (DOMA, 1981; Ambassade de France au Japon, 1982; MITI, 1982). DORD has patented nodule metallurgical processes in Japan and West Germany, but it has not been possible to examine the nature of these processes.

Development of a manganese nodule mining system has been designated since 1981 as one of eight national "Large Scale Projects," with a projected 1981-1989 budget of around $86 million (AIST, 1982). The Japanese government, through MITI's affiliate Agency of Industrial Science and Technology (AIST) which administers the projects, will own all plant and equipment as well as data developed under its programs (GAO, 1983). The current plan is to develop capability up to the point of commercializaton and then to select private operators for subsequent commercial activities, with the Japanese government absorbing all financial obligations imposed on the resulting enterprise by the International Seabed Authority (GAO, 1983). As shown in Exhibit 7, AIST assigns exclusive rights for all national-industrial "know-hows" possessed through the Large-Scale Project to a non-profit organization, Japan Indutrial Technology Association (JITA). JITA, in turn, acts as the licensor to qualified private companies (AIST, 1982). The 1982 budget for the manganese nodule mining project is compared to budgets for other current Large-Scale Projects in Exhibit 8.

In addition to sponsoring R&D activity and supplying low, fixed interest rate loans with conditional repayment schedules, the Japanese government also operates a program by which Japanese companies may cope with the LOS investment burdens through government-subsidized political risk insurance and mine finance insurance, both administered by the Metal Mining Agency of Japan (MMAJ) to require premiums at rates much lower than required by private insurers (GAO, 1983).

Summary descriptions of the various government and semi-government agencies and organizations with major roles in the Japanese seabed mining efforts are provided below. Comprehension may be aided by reference to Exhibit 6.

Ministry of International Trade and Industry (MITI). In the mid-1970's MITI established an emphasis in its marine development activities on ocean energy, desalination of seawater, recovery of dissolved minerals, enhanced use of littoral and offshore spaces, and exploration and recovery of manganese nodules (Ishikura, 1976). MITI embarked on a five year plan in 1973 designed to lead to a full-scale development program beginning in the early 1980's (Chilton, 1977). MITI's efforts in seabed mining have been channeled largely through its affiliate agencies: Agency for National Resources and Energy (ANRE); Agency of Industrial Science and Technology (AIST); and Metal Mining Agency of Japan (MMAJ).

A $6.3 million survey vessel financed directly by MITI through MMAJ was delivered in 1974 and used by the Geological Survey of Japan and DOMA to conduct exploration in the North Pacific. MITI was a significant contributor throughout the period of international efforts to develop and test the CLB system.

Agency for National Resources and Energy (ANRE). An affiliate of MITI, this agency contains the Oceanic Development Office (ODO) with major responsibilities for exploration activities. ODO's budget in 1977 was approximately $1.1 million (Chilton, 1977).

Agency of Industrial Science and Technology (AIST). AIST has been responsible for the coordination of analyses and the development of mining techniques (Chilton, 1977). AIST contains the Geological Survey of Japan and the National Research Institute for Pollution and Resources (NRIPR). The latter agency has been responsible for development, research on methods for collection and extraction of manganese nodules (Chilton, 1977). The Geological Survey of Japan is responsible for bathymetry and general marine geological studies. As noted, AIST manages the national Large-Scale Project.

Metal Mining Agency of Japan (MMAJ). MMAJ, as a public corporation, is only a semi-governmental group. It is empowered to execute ODO directions for exploration activities. In 1977, MMAJ was reported to have spent $1 million on deep ocean exploration (Chilton, 1977). Between 1976 and 1981 MMAJ spent over 1.2 billion yen ($4.6 million 1981 dollars) for exploration (GAO, 1983). Between 1975 and 1981, the agency spent over 11 billion yen ($42 million 1981 dollars) on technological R&D for nodules (GAO, 1983). The agency has extended loans at a subsidized interest rate of 6.75% (repayable over 8 years maximum with a one year grace period) to any Japanese firm investing in nodule exploration (Chilton, 1977). These loans have been an important source of support for DOMCO's activities as part of OMI. MMAJ conducted extensive operations with its research ship Harurei-Maru since 1975.

Deep Ocean Minerals Association (DOMA). DOMA has already been described in some detail. It is a "public benefit association" formed in 1974 with MITI's authorization with the objective of serving the Japanese economy by ensuring supplies from deep ocean minerals.

Japan Marine Science and Technology Center (JAMSTEC). This is a semi-governmental center under the Science and Technology Agency, which is a mini-ministry responsible directly to the Prime Minister's Office. JAMSTEC is composed of private contributor companies, providing about half its funding, receiving the other half from the government. JAMSTEC directorship comes from the government. The Science and Technology Agency is reported to have a budget of approximately $2 billion, spread over a variety of responsibilities including energy development, nuclear regulation and patent control. JAMSTEC has tended to operate somewhat independently of the MITI complex more directly involved in seabed mining projects. After some initial support for development and testing of CLB systems, JAMSTEC reduced its interest in seabed mining. Responsibility for nodule surveys passed to the Geological Survey in MITI's affiliate AIST. Currently, however, it is initiating, together with RIOE and DOMA, a study program for the potential of marine polymetallic sulfides deposits.

Research Institute for Ocean Economics (RIOE). RIOE is a small research center, organized as a voluntary corporation under the jurisdiction of the Ministry of Agriculture, Forestry, and Fishery and MITI. Its objective is to contribute to industrial strength of ocean development through research aimed at business opportunities for the Japanese ocean industry (RIOE, 1983). Government support is supplemented by membership contributions from private companies.

Japan Ocean Industries Association (JOIA). JOIA was organized in 1973 to coordinate the development of ocean resources. It is basically a trade association oriented toward information dissemination and international promotion, but much of its work is supported by government funds. These come primarily from MITI and the Ministry of Transportation.

Academic Support. Academic research is also carefully coordinated with national policies and directions in the development of seabed mining capability. Such research has been conducted at Tokai University (submersible construction, early CLB tests), Kyoto University (metallogenesis studies), Nara University (metallogenesis studies), and Yamaguchi University (mineral processing).

MITI officials are reported to feel that substantial improvements in the LOS Convention would be required to permit "free market" development of seabed mining (GAO, 1983). As a populous, resource-poor, industrial economy, Japan is especially interested in maintaining friendly relations with less developed supplier nations. Japan has signed the LOS Convention, and has been a participant in PrepCom. Japan enacted domestic seabed mining legislation on July 20, 1982, but the Japanese are not a party to the Interim Agreement. In fact, in February, 1982, DORD, the Japanese domestic seabed mining enterprise and national representative in international claims resolution, announced officially that Japan would not participate in a reciprocating states arrangement or "mini-treaty" outside the LOS process. Nonetheless, the Japanese have been involved in international discussions associated with the Interim Agreement and the private Industry Arbitration Agreement. DORD has recently acceded to the Industry Arbitration Agreement in order to resolve conflicts with the other commercial consortia.

FEDERAL REPUBLIC OF GERMANY

From 1970 through 1982 approximately 80 million Deutsche Marks (DM) ($26.7 million 1975 dollars) are estimated to have been provided by the Federal government to seabed mining development, mostly through direct grants (GAO, 1983). The Economics Ministry is reported to have expressed the view that the creation of a government sponsored or financed national enterprise is out of the question (GAO, 1983).

(BUT: Schusten (1976) and Chilton (1977) report that 95 million DM were spent by the government on seabed mining in 1971 alone, and 180 million DM in 1974. Schusten's (1976) partial estimate of spending through 1975 is 700 million DM, and nearly 1 billion DM were estimated to have been budgeted for the period 1976-1979 (Chilton, 1977). The discrepancy can probably be explained as follows: The earlier reports of Schusten and Chilton were made at a time when efforts were underway to build support for national efforts in seabed mining. It is probable that very inclusive measures of FRG support were therefore employed, counting virtually any spending that might be presumed to benefit seabed mining.)

The proportionate breakdown for government contributions during the period 1970-1974 have been reported by Schusten (1976) and Chilton (1977) as: FRG, 70%; industry, 16%; German Research Society, 11%; and coastal states, 3%. Since the formation of Ocean Mining Associates in 1974, the FRG has continued to provide approximately half the funds for the German group, Arbeitsgemeinschaft Meerstechnischgewinnbare Rohstaffe (AMR) (Chilton, 1977). Although one partner in the AMR group, Salzgitter, is wholly-owned by the FRG government, AMR officials stress that Salzgitter's participation is conducted strictly on a business basis and at arms length from its governmental owner.

FRG assistance to seabed miners has taken two basic forms: 1) exploration promotion loans administered by the Economics Ministry; and 2) research and technology grants from the Ministry for Research and Technology (BMFT) (GAO, 1983). Of the roughly $26 million (1975 dollars) devoted to nodule mining by the FRG since 1970, over 90% (about $24 million) has been through direct grants while less than 10% ($2 million) has come through exploration promotion loans (GAO, 1983).

Primary government funding comes from the Bundeministrium fur Forschung und Technology (BMFT), the Ministry for Research and Technology. BMFT makes direct grants to private firms as well as research institutions for research and technology development consistent with national goals. Over the period 1970 to 1979, DM 65 million ($21 million 1975 dollars) are estimated to have been awarded for ocean mining (GAO, 1983). This is only a small portion of the BMFT's total awards, however. Of a 1982 BMFT budget of DM 128 million, only 5.5% (DM 7 million) was targeted for ocean mining (GAO, 1983). Largely through its program for the exploration for raw materials on and beneath the seafloor, BMFT has been responsible for governmental coordination and funding of German seabed mining activities. BMFT is now reported to place a low priority on ocean mining research (GAO, 1983).

The government provided funds to charter Deepsea Venture's R/V Prospector in 1970 and 1971 (CRS, 1975). Since private firms converted a stern trawler to the nodule exploration vessel, R/V Valdavia, in 1972, the Ministry for Education and Science chartered the ship for four years of nodule survey work (CRS, 1975). A sister ship, R/V Sonne, was also built with government subsidies. Total funding for the four-year period 1972-76 has been estimated at between 40-50 million DM. BMFT also makes grants to universities for related research and subsidizes AMR research cruises.

The Ministry of Economics is another major focus for government involvement in seabed mining efforts. The Ministry of Economics' exploration promotion loan program provides interest-free loans toward exploration costs that are repayable only in the event of successful mining. The loan program, begun in 1971, normally covers 50% of project costs but in some cases may be extended to 75% if new methods are being developed (GAO, 1983). Since 1972 only about $2 million (1975 dollars) has been provided for seabed nodule exploration, compared to total loan obligations through 1979 of nearly $60 million (1975 dollars) (GAO, 1983).

The Ministry of Economics was actively involved in promoting the creation of the AMR group in 1972: "High risks and expense, labor division, and the prospect of an increase in know-how induced several German companies interested in raw materials supplies to enter into negotiations regarding the creation of a consortium, also encouraged by the competent Federal authorities" (emph. added) (Metallgesellschaft, 1975). The Ministry of Economics provides the government with evaluations of scientific and technological progress by contracting with private contractors and research institutions. The Ministry of Economics includes an office for geosciences and raw materials which conducts some research on the topic and supports a minor research effort at universities (Chilton, 1977).

An important group influencing the scale and direction of FRG involvement in seabed mining efforts is the Wirtschaftsuereinigung Industrieller Meerstecknik (WIM), a trade association and study group of German marine technology firms.

Research projects at academic institutions are a significant form of government support for development of seabed mining capabilities in Germany, and such projects are consciously designed to accomodate both governmental and industrial interests in the results. Such research, 100% funded by the BMFT through the Deutsche Forschingsgesmeinschaft (German Research Association) has taken place at Aachen, Clausthal, Cotlingen, Kiel, Hohenhein, and Munchen (Chilton, 1977).

The FRG has refused to sign the LOS Convention and is a party to the Interim Agreement. West German domestic seabed mining legislation was passed August 22, 1980, and OMI originally filed for a 559,000 square kilometer exploration area under that law. In addition to this claim, it has been reported that AMR has filed a separate license application in West Germany. Through its ownership of Salzgitter and, more particularly, through its financial sponsorship via BMFT, West Germany has a direct interest in prospects for seabed mining activities. The government's support of West German industry involvement appears to have been motivated by a concern for the long-run strategic importance of seabed metal supplies.

FRANCE

The French government has, through direct governmental outlays, contributed more than 90% of the over $50 million invested in the French seabed mining consortium. Unlike the Japanese, France has no involvement in international or multinational commercial seabed mining enterprises.

France has a two-pronged domestic mining program, with the mixed-form AFERNOD and, more recently, with the governmental enterprise GEMONOD. The leading organization has been the French national agency for development and exploitation of ocean resources, IFREMER (formerly Centre National pour l'Exploitation des Oceans or CNEXO) which accounts for about 70%. The next major partner is also an agency of the French government, the extensive Commissariat a l'Energie Atomique (CEA) accounting for about 20%. Early in the history of AFERNOD, the French equivalent of the Bureau of Mines and

Geological Survey, Bureau de Recherches Geologiques et Minieres (BRGM), was briefly involved. BRGM withdrew quickly, however, in the belief that seabed mining development was economically premature. There is some reason to believe that CEA will play a more dominant role in the new GEMONOD. Although there has been little development or exploration activity since 1979, the French government is reported to have budgeted $17 million for seabed mining in 1982 (GAO, 1983).

Both IFREMER and CEA are public establishments, but they try to operate independently under private decisionmaking rules. They are Public Industrial and Commercial Establishments, like SNCF, the French National Railway Company, and Air France, the national airline. Though the ownership shares are 100% government held, both agencies attempt to operate as independent research organizations. CEA with a 1982 budget of about 8 billion French Francs ($1.2 billion 1982), about 4 BFF civilian and 4 BFF military, is a complex group with approximately 100 subsidiaries, all of which are commercial enterprises.

Like West Germany, France takes a long-term strategic view of the value of a seabed mining stake. Consistent with this attitude, the French effort appears to be cognizant of and responsive to the activities of other nations. Some French officials have stated privately that they would love to see an end to French spending on seabed mining efforts, if only the Japanese would stop. The French effort has been motivated more by political and bureaucratic interests than by economic ones. French sources have cited a desire for prestige and honor. Seabed mining seemed well suited for CNEXO's mission to promote exploitation of ocean resources, and CEA had applicable experience in minerals management and processing, as well as expertise in hydraulics and fluid dynamics. Some sources also voice the impression that CEA is an expansive bureaucracy with a large, technologically progressive engineering staff to keep busy.

With typically Gallic diplomatic verve, the French are party to the Interim Agreement as well as active participants in the PrepCom proceedings. Though France has signed the LOS Convention, it is delaying ratification until the work of PrepCom on the rules and regulations of the ISBA can be examined. France qualifies as a pioneer investor under PIP. The French domestic seabed mining law was enacted on December 23, 1982.

OTHER NATIONAL GOVERNMENTS

In addition to the roles that some play in supporting or participating in seabed mining enterprises, national governments are central actors in the creation of a legal regime for seabed mining because it is they that: (1) negotiate and are parties to international agreements securing rights to exclusive area access (PIP under LOS, for example, or interim international agreements toward formation of a reciprocating states agreement); (2) direct, regulate, or condition activities of the seabed mining enterprises or organizations operating under their jurisdiction; and (3) act on behalf of such enterprises or organizations as "certifying states" for the purposes of PIP.

The United States probably bears the most varied responsibility in this regard, although it has refrained from any direct financial involvement in commercial seabed mining development. Whatever the international composition of their membership, three of the major international commercial consortia -- OMCO, OMI, and OMA -- operate as U.S. business entities. And substantial interests are held by U.S. companies in four. The activities of these groups have qualified the U.S. enterprises as pioneer investors under PIP, but the United States has not qualified to "certify" them for that status. The United States, has, of course, refused to sign the Convention and refused to participate as an observer at or help finance the PrepCom. The United States was an originator of the Interim Agreement of September 2, 1982, and has been promoting the establishment of a Reciprocating States Arrangement outside the LOS framework.

The United Kingdom abstained in voting on adoption of the LOS Treaty Text and has also refused to sign the LOS Convention. Her Majesty's Government is, however, attending PrepCom as an observer by virtue of having signed the Final Act. Great Britain is a party to the Interim Agreement and apparently has been active in promoting the arrangements contemplated by that agreement. British domestic seabed licensing legislation was passed on July 28, 1981 (20 I.L.M. 1217-27, 1981). In 1974, the British government made a loan to RTZ and Consolidated Gold Fields of £ 830,000 under the Science and Technology Act of 1965 (House of Commons, 1981). This was to assist the two companies to enter the Kennecott consortium. Repayment of the loan is contingent on commercial production. The British companies are also obliged to make their share of the group's metal output available first for consumption by British customers (House of Commons, 1981). In 1977, British Petroleum was brought into the consortium through the purchase of half RTZ's share and assumption of half of RTZ's government loan responsibility. Throughout most of the postwar period, the British government has held about 50% interest in BP, with reserved seats on the Board of Directors. More recently, however, the government share in BP has fallen to about 40%. There is no reason to suppose, however, that government ownership participation in BP significantly influences that company's seabed mining decisions.

Italy has so far declined to sign the LOS Convention. The Italian government's interest in seabed mining is motivated by strategic national supply considerations (Bastianelli, 1981, 1982). Although Italy was not a party to the Interim Agreement, Italians have been involved in discussions pursuant to that agreement because of the Italian national oil company's, ENI's, nearly 25% share in OMA. Indeed, the "hurry and spend to catch up" role that the Italians have played in that group can be seen as motivated in part, at least, by an effort to qualify under the terms of the Interim Agreement or of PIP.

Belgium has not signed the LOS Convention. Like Italy, the Belgian government is not a party to the Interim Agreement, but is nonetheless participating in associated negotiations and discussions under the auspices of that agreement because of Union Miniere's more than 25% share of OMA. Belgium is attending the PrepCom proceedings in an observer role.

Canada has a major stake in seabed mining: not just because of INCO's 25% share of OMI and Noranda's 12% of KCON, but because Canada is a major international nickel producer and a principal beneficiary from the terms of LOS. Canada has signed the LOS convention and has played an active role in the conflict resolution activities of PrepCom. Although Canada is not a party to the Interim Agreement, there is some indication that the Canadian government has been involved in discussions and subsequent agreements associated with the Interim Agreement.

The Netherlands has an interest in seabed mining because of the nearly 40% share of OMCO held by two Dutch companies, Billiton (a Royal/Dutch Shell subsidiary) and Bos Kalis. Billiton is withdrawing from the consortium and Bos Kalis has declined to continue active participation, choosing instead to let its share dilute if the other partners continue to invest. Holland has signed the LOS Convention and is a participant in PrepCom. While the Dutch government is not a party to the Interim Agreement, it may have become involved to some extent in associated multilateral discussions because of the Dutch companies' position in OMCO.

Other countries that have shown an interest in conflict resolution through their activities at PrepCom, and that might conceivably attempt to qualify as Pioneers under PIP include Australia, Egypt, Finland, Indonesia, Kuwait, Norway, Pacific archipelagic states, Sweden, and Spain. Norwegian companies have been employed as contractors by the international consortia, and the Norwegian government has sonsored R&D activities through the "Deep Ocean Nodule Mining Project," apparently to explore the potential of Norwegian enterprise as a supplier to seabed mining industry. None of the other countries is known to have any direct involvement in seabed mining development or exploration, and none has staked a claim to any prospective mine sites.

3. ECONOMIC STATUS OF OCEANIC COBALT-BEARING CRUSTS

The Recent Interest in "Cobalt Crusts"

Ferromanganese oxide encrustations have long been recognized as a basic form of the deepsea ferromanganese oxide concretions that also include abyssal manganese nodule deposits (Cronan, 1977). Knowledge of these variable occurrences dates to the HMS Challenger samples of 1874, but much remains to be learned about their origins (Kerr, 1984). Recent interest in the economic potential of the crusts derives essentially from the work of Mero (1965) on manganese nodules as a resource. As economic interest in the manganese nodules has been dwindling in the last five years, marine scientists have begun touting the potential of the crusts associated with seamounts. In fact, far too little is known about these mineral occurrences, or more importantly about how they might be commercially exploited, to support claims that they are economically important.

Costly ship-time is required to explore for the thickest and richest deposits, and there is no assurance that even these would ever be suitable for

commercial recovery. A fundamental technical shortcoming is that the thin encrustations typically are cemented fast to a hard-rock substrate. Recovery of any of the barren substrate would diminish the effective, working metal grade of the recovered bulk of material. No method is known by which the crusts can be selectively recovered in quantity without some substrate material. Further, it would appear that the metal grades of crusts sampled so far have often been reported on a dry-weight basis, which tends to discount the gangue-like quality of contained moisture and the cost of handling and removing water from the recovered ores in a prospective mining operation. These severe limitations have led one distinguished marine geologist to describe the crusts as only an interesting mineral curiosity (Emery, pers. comm., 1984).

Several features of the ferromanganese crusts have been suggested by Craig, Andrews and Meylan (1982), by Halbach, Manheim and Otten (1982), by Clark, Johnson, and Chinn (1983), and by Halbach and Manheim (In press) as favoring the crusts' potential as a commercial target:

1) They may be richer and more extensive than previously thought.

2) They may be technologically easier because they are shallower than prime manganese nodules and because the crusts may break away from the substrate.

3) Located on sea mounts, many sites will be inside national Exclusive Economic Zones.

4) Cobalt is considered a strategic metal.

5) Some sampled crusts are thick and rich enough to permit extrapolation to contained metal values exceeding those of prime nodule sites' on a $/unit-area basis and about equal to nodules' on a $/unit-weight basis.

6) Richer in cobalt than are nodules, the crusts are favored by the relatively greater rise in cobalt price than in nickel price over the past decade.

As will be apparent below, however, many of these supposed advantages are based on extremely limited information, on comparisons to manganese nodule deposits that are themselves of limited economic value, and on pure conjecture.

Nature and Distribution of the Crusts

Ferromanganese crusts appear to be worldwide in distribution, occurring under favorable conditions throughout the world's oceans. Exhibit 9 shows the locations where samples of the crusts have been recorded. The most favored sites for cobalt-rich, thick encrustations seem to be seamount slopes and plateaus in 1-2 km of water in the Central Pacific (Halbach and Manheim, In press). Several such locations occur within the newly-established United States Exclusive Economic Zone (EEZ). The extent of the U.S. EEZ is indicated in Exhibit 10. Locations where ferromanganese crusts have been sampled in the

U.S. EEZ or where they are expected to occur are shown in Exhibits 11-14. Note that nothing is implied about the richness of deposits in these locations, only that crusts have been identified or inferred there.

The ferromanganese crusts tend to occur on consolidated rock surfaces in raised areas of the sea floor that are too steep to permit permanent sediment accumulation or where sediments are swept away by strong currents. The crusts can be distinguished in two basic forms dependent on the depositional environment (United Nations, 1982). One form is as a layer or layers of manganese and iron oxides coating the surface of a rock outcrop. This rock encrustation is the form characteristic of seamount slopes and ridges. Most common substrates encountered by Halbach, Manheim and Otten (1982) in the Central Pacific Basin are: 1) alkalic basalt and its alteration products, 2) hyaloclastics with fragments of basalt, 3) yellowish-green montmorillonitic altered rock, 4) phosphorite rock, and 5) occasionally soapstone. Or, crusts may occur as a pavement of hard manganese and iron oxides covering a portion of the ocean floor. In some places, these pavements consist of nodules cemented together by manganese and iron oxides. Even though its terrain is only gently sloping, wide areas of the Blake Plateau off the coast of South Carolina are covered by crust pavements, possibly in part because Gulf Stream currents sweep away sediments (Manheim, Ling, and Lane, 1983). However, crusts having high cobalt content (of about 1% or more) have been found to date primarily in the Pacific Ocean.

The ferromanganese crusts subject to recent economic claims are generally found associated with depositional settings and surrounding environments different from those in nodule areas (Manheim, Ling, and Lane, 1983). Except at places, such as on the East Pacific Rise, where hydrothermal mineralizations are being formed, the crusts seem to grow as slowly as any ferromanganese oxides in the ocean. It is therefore believed that the oldest seamount formations, especially 20-30 million years old, are likely to have the thickest accumulation of crust.

The bathymetry in these regions can be steep and rugged, with slope inclinations of around 50° just beneath the summit (Halbach, Manheim and Otten, 1982). Exhibits 15-17 show seismic reflection profiles of slope relief in various seamounts of the Hawaiian chain and Midway Island area (Craig, Andrews, and Meylan, 1982). The average inclination of slopes investigated by Halbach, Manheim and Otten (1982) were about 14°. No ferromanganese deposits were detected by these investigators "in the intervening valleys." On the Hawaiian seamounts, Craig, Andrews and Meylan (1982) found that substrate type and seafloor relief on deep terraces vary considerably over distances of as little as a few meters, from patches of smooth sediment to basalt escarpments.

Several other correlates with cobalt enrichment in ferromanganese oxides have also been proposed and supported by available evidence:

* The highest concentrations of cobalt are found in ferromanganese material of hydrogenetic origin, which mainly are distributed in seamount regions (Halbach, Hebisch and Scherhag, 1981).

* Cobalt and nickel content are inversely related to depth, so that higher cobalt grades are encountered in shallower water (Halbach and Manheim, In press). Exhibit 18 shows this relationship as measured at stations in the Central Pacific Basin (Halbach and Manheim, In press). Cobalt concentrations in their samples increase from less than 0.4% at water depths of more than 4 km to 1.2% on seamount slopes and tops in less than 2.5 km of water.

* Cobalt enrichment may be greatest in the uppermost layers of a crust (Halbach and Manheim, In press). This effect is illustrated with a sample in Exhibit 19, where the sample is cobalt-enriched in the upper layer of 2 cm, underlain by oxides containing about 0.5% cobalt.

* The metal content of crusts may be more critically influenced by composition of the ambient water than are abyssal manganese nodules, which may be controlled more by substrate composition (Manheim, Ling, and Lane, 1982). Crust thickness and chemical composition appear to show no relationship to substrate composition (Craig, Andrews and Meylan, 1982).

Crust thickness appears to be extremely variable, depending on local conditions which vary over a scale of meters. Craig, Andrews and Meylan (1982) report thickness ranges of 1-10 mm near the island of Oahu to 2-50 mm near Midway island. They cite earlier dredge samples showing variation in crust thickness of 0.5-20 mm over distances of a kilometer or so, and they state that wide variations in crust thickness are often found within a single dredge haul in most localities. Where the crusts form as pavements on sedimentary substrate, Craig et al. (1982) find crusts of 2-4 cm thickness. Halbach and Manheim (In press) report mean crust thickness of over 2 cm in upper slope areas of sampled seamounts at water depths of 3 km or less. They report some crust samples reaching a maximum thickness of 7-9 cm.

The mean composition of about 26 samples taken by Halbach and Manheim (In press) above a depth of 4 km in the Central Pacific Basin during the MidPac '81 cruise is shown in Exhibit 20. The mean cobalt content of the samples is 0.79% with a standard deviation of 0.33.

Exhibit 21, compiled by Clark, Johnston and Chinn (1983), shows an average cobalt content of 0.90 in 57 selected samples from depths of less than 2.4 km in the central Pacific. In Exhibit 22, also compiled by Clark, Johnson and Chinn (1983), cobalt content averages 0.38% for 27 samples selected from 47 available from the Hawaiian archipelago, with a range of 0.41% up to 1.64%. In the same exhibit, 30 samples reported by Halbach from depths between 0.8-2.4 km in the Central Pacific show an average content of 0.92% and a range of 0.48% to 1.92%. All cobalt grades appear to be reported on a dry-weight basis.

Results of samples taken during a recent cruise by the U.S. Geological Survey vessel S.P. Lee have not yet been reported in the literature, but press reports state that "thin pieces" of crust with cobalt concentration of up to 2.5% were recovered (Ocean Science News, 1984). Ambiguity in the printed accounts, however, makes it impossible to tell if this high grade was found only in the cobalt-enriched upper layer of a thicker crust or was the grade

for an entire crust sample. Halbach and Manheim (In press) had already reported cobalt content of over 2.0% in the "top 0.5-cm-thick layer" of some seamount crusts, but this layer is cemented to cobalt-poorer layers underneath. Results from the Lee expedition are also said to indicate that the relationships between crust thickness, seamount type, geological structure, topography, and water depth are more complex than had been thought based on earlier work (Ocean Science News, 1983). Furthermore, much steeper slopes were encountered than had been mapped in earlier work and crust coverage was more uneven than expected (Manheim, pers. comm., 1984).

Coverage and Limitations of Crust Data

Much of the scientific work on ferromanganese crusts has been generated as a kind of adjunct to research on the more economically-interesting manganese nodules. Locations where crust samples have been recorded are shown in Exhibit 9. Most information is located in the Scripps Institution manganese nodule data base, where sample data of varying quality is available on some 10,000 nodule observations. In the Scripps data base, chemical analyses were found to be associated with 639 crust samples (Manheim, Ling and Lane, 1983). Several hundred additional crust specimens and data on a total of 654 stations from eight other institutions are now being processed by the U.S. Geological Survey in Woods Hole (Manheim, Ling and Lane, 1983). Thickness and content analyses in Halbach and Manheim (In press) appear to be based on only 26 samples from 117 testing stations. Average grades compiled by Clark, Johnson and Chinn (1983) are based on a selection of 57 samples. Their reported grades for the Hawaiian archipelago are based on a selection of 27 samples from 47 available, and their reported grades for the Johnston-Palmyra region are based on 30 samples.

It is apparent that crustal thickness and composition reports in the literature are based on extremely limted samples taken under uncertain conditions over broad swaths of ocean terrain. Craig, Andrews and Maylan (1982) emphasize that additional survey work with resolution on scales of meters to kilometers is required before confident assessment of the potential resource could be attempted. 150 stations recorded by Glasby et al. (1980) in the Southwestern Pacific Basin provide a sample density of only one sample per 60,000 km^2. On that basis, no real indication of localized variation could be made over distances of less than 100 km^2 (Clark, Johnson and Chinn, 1983). Further, even single dredge hauls are taken over large distances and often result in a great variety of samples. No method now exists for determining the exact source of each sample. Because interest in some sampling efforts focused on manganese nodules, great care was not always taken to record crust data on a consistent basis (Manheim, pers. comm., 1984). Some sample analyses may contain large amounts of substrate materials, while others may be limited to only a single layer of the crust.

Economic Claims and Reported Metal Value In-Place

In spite of the severely limited data base, reports of economic value associated with ferromanganese crusts have begun to appear (Eos, 1984). Exhibit 23 shows the comparison of in-place metal value made by Clark, Johnson

and Chinn (1983) between cobalt crusts from a hypothetical "prime minesite" and manganese nodules. In 1982 $ value, the value per metric ton of crusts appears to exceed that of nodules, $247.74 compared to $213.84. It should be stressed, however, that the crust estimates are based on high values assumed to exist in some "prime minesite" because they have been observed as maxima in some crust samples. The estimated value of cobalt content in the hypothetical crusts exceeds that of nodules, $165.38 per metric ton compared to $33.08 per metric ton.

Similar calculations have been attempted by Halbach and Manheim (In press). Their results are shown in Exhibit 24. In this case the $/unit-weight value of metals in selected crust samples is about the same as for nodules, but the $/unit-area in-place values of the crusts exceed those of the nodules in every case: $3.50, $4.10, and $3.55 per m^2 compared to $1.75 per m^2. This is not greatly surprising, since denser crusts are assumed to provide greater areal coverage than do the nodules. Halbach and Manheim assume that crust coverage is only 40% of area, but they do not adjust downward their estimated grades to account for non-crust gangue recovered in the remaining 60%, implicitly assuming that the 40% area covered by crust can be mined with perfect discrimination by the recovery system. Implicit in the comparison of value per unit-area is is an assumption that in-place value per unit-area is a relevant point of comparison. This might be so if costs of recovery were controlled by area mined, but they are more likely to be dominated by mass of material handled.

In fact, estimated value of metal content of in-place minerals is of little economic use unless it is coupled with some appreciation of the cost of recovering that metal content. To learn that very high-grade cobalt deposits existed on Neptune, and that their value per unit weight was very high, would be of little economic interest unless there were also reason to think that they could be cheaply retreived from that planet.

Recovery Technology and Costs

However valuable the metal content of cobalt crusts might be, how that metal might be economically recovered and produced is now unknown. Indeed, merely sampling the crusts in a consistent fashion is technically difficult with existing technologies. Bischoff et al. (1983) suggest that detailed sampling on a single seamount, with several hundred samples systematically acquired, is necessary to answer the question of continuity of coverage. To do this, new samplers would have to be developed that could penetrate hard substrate and be positioned precisely on the seafloor. Traditional dredging covers too large an area during each haul to be useful for this purpose.

Certainly no known methods exist to recover the material on a commercial scale. As a special panel convened by the U.S. Interior Department to assess the state of engineering and technology for offshore hard minerals concluded: "Little or no technology exists for mining mineral deposits in the waters of 100 to 10,000 feet that occur in the EEZ, and adaptability of existing systems -- or parts thereof -- in dredging or deep sea nodule mining to the EEZ deposits and their physical conditions is essentially unknown" (DOI Panel,

1983). What is known is that a number of firms and governments spent a total of nearly $0.5 billion over the past decade in an attempt to develop a commercial capability to recover seafloor manganese nodules. That objective has not yet been attained, and a number of firms are withdrawing from the enterprise. In many ways — because the breaking of hard rock would seem to be required and because separation from hard substrates may be necessary, with lifting of variable-sized chunks of crust and rock rather than relatively uniform nodules — the technical problems of crust recovery appear to be greater than those associated with nodule recovery.

Remaining Effort to Achieve Confident Resource Valuation

Exhibit 25 shows the kind of information that is required in general to evaluate the commercial prospects of a class of minerals. Those factors headed as "Present and Prospective Demand Conditions" and "Long-Run Supply Conditions" basically apply to market factors that will drive the relative attractiveness of the minerals. Examination of these conditions is beyond the scope of this assignment in most cases. In the latter category, as noted, virtually nothing is now known of recovery technology and cost. In category B, "Characteristics of Deposits," we have seen that information on the nature of crustal deposits is still spotty and relatively primitive. According to Bischoff et al. (1983), "the areal extent, thickness, and composition of the crusts are still largely unknown."

Obviously a great deal of work and expense would be necessary before cobalt-bearing ferromanganese crusts could be seriously evaluated as a potential resource. When asked to place the stage of development of knowledge of the economic potential of cobalt crusts on the time scale experienced in the investigations of manganese nodules, one of the leading crust researchers chose 1963 (Manheim, pers. comm., 1984). That was in the very earliest period of commercial investigation of manganese nodules and was prior to virtually all the millions of dollars that were spent to learn that nodules were not yet an economically viable prospect. No reason is obvious why a comparable expenditure of time and money would not be required to push knowledge of the economic potential of ferromanganese crusts to the same level of certainty.

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Exhibit 1

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James M. Broadus
Policy Associate
Marine Policy & Ocean Management Center
Woods Hole Oceanographic Institution

Types of Information Sought in Interview for "An Economic Analysis of Industrial Structure and Behavior in the Emerging Seabed Mining Industry"

*Background and history of company's involvement in the "industry" and in the consortium.

*Motivating factors in company's participation. Why you and not others?

*Reasons for choice of particular organizational form and for identity of co-participants.

*How the nature or scope (main lines of business) of the parent companies affects their motivations, interests and behavior within the consortia and within the "industry."

*Key changes or milestones in your company's role within the consortium.

*The nature of rivalry or competition within the "industry" (and within the consortia), and the nature of forebearance or cooperation.

*The nature of government support or participation in your group and how that affects your objectives, constraints and behavior.

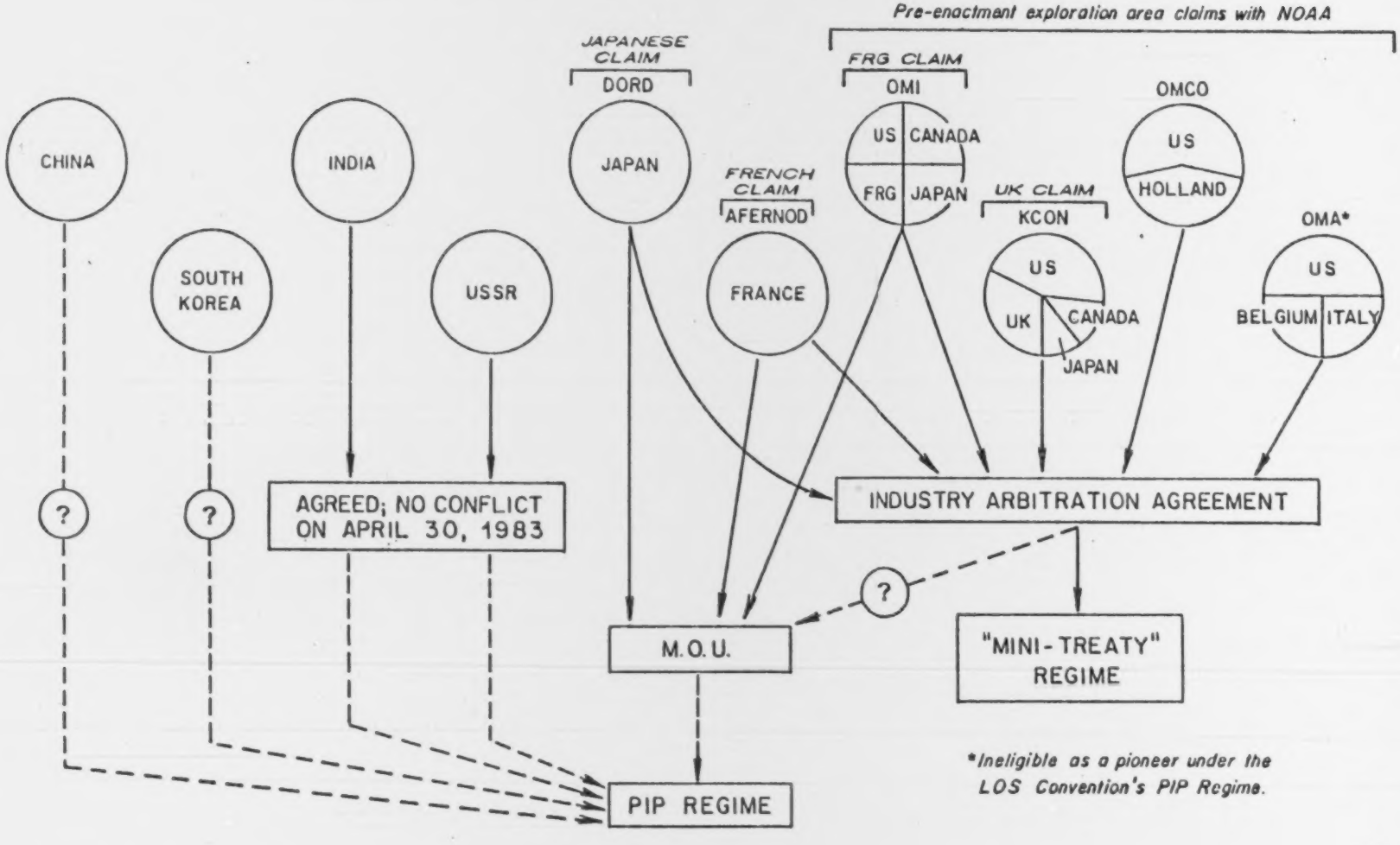
*Relative advantages enjoyed by incumbents in the "industry" that would have to be overcome by potential new entrants.

*Predictions of possible future reorganization or realignments within the "industry."

*Other suggested sources of information.

Exhibit 2

PARTICIPATION OF SEABED MINING ENTERPRISES IN CONFLICT RESOLUTION



Source: Broadus and Hoagland, Forthcoming

Exhibit 3

CORPORATE INTERESTS AND ACTIVITIES IN SEABED MINING

CONSORTIUM MEMBER & SHARE	PARENT	NATIONALITY	PARENT'S ANNUAL R&D 1980-81 (millions)	ESTIMATED SPENDING TO DATE (a) (millions)	GENERAL SCOPE OF PARENTS' OPERATIONS	TECHNOLOGICAL FO
KENNECOTT CONSORTIUM (KCON): formed January 1974				$50-60		
Kennecott Corporation (40%)	(SOHIO), BP	(U.S.), U.K.	$ 30.3		Petroleum production and trading; minerals production and metals trading (especially copper and gold); transportation; shipbuilding.	Metallurgical pr Kennecott): "cupr leach" process; t "vehicle" on a wir on a self-propell airlift system.
RTZ Deepsea Mining Enterprises Ltd. (12%)	Rio Tinto Zinc p.l.c.	U.K.	$ 22.1			
Consolidated Gold Fields p.l.c. (12%)	Consolidated Gold Fields p.l.c.	U.K.	$ 25.7 (1982)			
BP Petroleum Development Ltd. (12%)	British Petroleum Company p.l.c.	U.K.	$201.0			
Noranda Exploration Inc. (12%)	Noranda Mines Ltd.	Canada	$ 6.0			
Mitsubishi Corporation)	Mitsubishi Group (leader)	Japan	(b)			
Mitsubishi Metal Corp.) (12%)	"	Japan	(b)			
Mitsubishi Heavy Industries Ltd.)	"	Japan	(b)			
OCEAN MINING ASSOCIATES (OMA): formed May 1974				$130		
Essex Minerals Company (=25%)	U.S. Steel Corporation	U.S.	$ 74.0		Petroleum production and trading; refined petroleum products; minerals production and metals trading (especially copper, lead, zinc, and others); steelmaking; other energy sources.	Deepsea Ventures contractor) has t "towed dredgehead hydraulic recover and hydrochloric process.
Union Seas Inc. (=25%)	(Union Mines, Union Miniere S.A.), Société Générale de Belgique	Belgium	$ 5.5			
Sun Ocean Ventures (=25%)	Sun Company Inc.	U.S.	$ 50.0			
Samin Oceana Inc. (=25%)	Ente Nazionale Idrocarburi (ENI)	Italy	$162.0			
OCEAN MANAGEMENT INCORPORATED (OMI): formed February 1975				$45-50		
Inco Inc. (25%)	Inco Ltd.	Canada	$ 30.9		Minerals production and metals trading (especially nickel and others); contract offshore drilling and support operations; steelmaking; construction machinery; banking; engineering; general trading; wire rope manufacturing.	Inco, West German companies have fo sledge hydraulic has focused on a sulfuric acid lea process.
SEDCO Inc. (25%)	SEDCO, Inc.	U.S.	$ 12.4			
Arbeitsgemeinschaft Meerestechnische Rohstoffe (AMR) (25%)	(Metallgesellschaft A.G.	F.R.G.)				
	(Preussag A.G.	F.R.G.)	$ 51.6 (c)			
	(Salzgitter A.G.	F.R.G.)				
Deep Ocean Minerals Company (DOMCO) (25%)	23 Companies led by Sumitomo	Japan	(b)			
OCEAN MINERALS COMPANY (OMCO): formed November 1977				$120		
Amoco Ocean Minerals Company (=31)	(Amoco Minerals), Standard Oil	U.S.	$150.0		Missiles; space; electronics; aircraft manufacturing; petroleum production and trading; refined petroleum products; offshore dredging; pipelines.	Lockheed has pater controlled, botto hydraulic recover temperature, sulfi metallurgical proc examined.
Lockheed Systems Company) (=31)	(Lockheed Corporation	U.S.	$100.0			
Lockheed Missiles and Space Company))	((Lockheed Corporation	U.S.				
Billiton B.V. (=31)) Ocean Minerals Inc.	(Royal Dutch/Shell	Netherlands	$568.8			
B.K.W. Ocean Minerals B.V. (=8))	(Royal Boskalis Westminster	Netherlands	$ 4.0			
ASSOCIATION FRANCAISE POUR L'ETUDE ET LA RECHERCHE DES NODULES (AFERNOD): formed 1974				$83		
Centre National pour l'Exploitation des Océans (CNEXO) (=70%)	French Government (d)	France	$ 62.7		Oceanography; nuclear power; metallurgy; minerals production and metals trading; (especially nickel and cobalt); shipbuilding.	AFERNOD has spread CLB, towed-sledge the remote-control shuttlecraft (PLA)
Commissariat à l'Energie Atomique (CEA) (=20%)	French Government	France	N.A.			
Société Métallurgique le Nickel (SLN) (6%)	IMETAL, Elf Aquitaine	France	$ 3.3 (SLN)			
Chantiers du Nord et de la Méditérrande (CNM) (4%)	Schneider S.A.	France	$132.2 (1982)			
DEEP OCEAN RESOURCES DEVELOPMENT CORPORATION (DORD): formed September 1982				$42 (e)		
48 Companies (including the members of the Deep Ocean Minerals Association (DOMA)) that coordinate activities with MITI (b)		Japan	$ 61.8 (1982) (b)		General trading; steelmaking; shipbuilding; transportation; ferrous and nonferrous metallurgy; industrial machinery; chemicals; metals trading; cable manufacturing; pump manufacturing.	DORD companies foc Hasuda's CLB. Has under MITI's large they have been dev sledge, hydraulic Metallurgical proc

(a) Estimated total spending in current dollars as spent, not constant dollars (Ocean Industry, 1983; U.S. Congress, 1981).

(b) Japan's Ministry of International Trade and Industry (MITI) has made loans to Japanese companies participating in the multinational seabed mining consortia. For example, in 1976-78, approximately $9.25 million was loaned by MITI. MITI's affiliate Agency of Industrial Science and Technology (AIST) has initiated the development of a seabed minerals recovery system as a "large scale project." AIST's total 1982 Large Scale Project Budget (seabed mining and all other projects) is shown in the Parent's Annual R&D column for DORD.

(c) The figure is the 1982 budget for West Germany's Federal Ministry of Research and Technology (Bundesministerium für Forschung und Technologie or "BMFT"). BMFT has supported about 50% of AMR activities since 1975.

(d) CNEXO is in the process of merging with the French fisheries agency, ISTPM, to form a new agency called: Institute Francaise de la Recherche et l'Exploitation de la Mer (IFREMER).

(e) Estimated nodule R&D spending by the Metal Mining Agency of Japan (MMAJ) in 1976-81 (GAO, 1983).

ACTIVITIES IN SEABED MINING

	PARENT	NATIONALITY	PARENT'S ANNUAL R&D 1980-81 (millions)	ESTIMATED SPENDING TO DATE (a) (millions)	GENERAL SCOPE OF PARENTS' OPERATIONS	TECHNOLOGICAL FOCUS	STATUS AND COMMENTS
				$50-60			
	(SOHIO), BP	(U.S.), U.K.	$ 30.3		Petroleum production and trading; minerals production and metals trading (especially copper and gold); transportation; shipbuilding.	Metallurgical processing (led by Kennecott): "cuprion and ammoniacal leach" process; have tested a towed "vehicle" on a wire; holds patent on a self-propelled "tractor" and airlift system.	Virtually inactive since 1976. Have filed for NOAA exploration licenses of 173,000 km^2. Also filed in U.K. BP controls Kennecott through SOHIO.
	Rio Tinto Zinc p.l.c.	U.K.	$ 22.1				
	Consolidated Gold Fields p.l.c.	U.K.	$ 25.7 (1982)				
	British Petroleum Company p.l.c.	U.K.	$201.0				
	Noranda Mines Ltd.	Canada	$ 6.0				
	Mitsubishi Group (leader)	Japan	(b)				
	"	Japan	(b)				
	"	Japan	(b)				
				$130			
	U.S. Steel Corporation	U.S.	$ 74.0		Petroleum production and trading; refined petroleum products; minerals production and metals trading (especially copper, lead, zinc, and others); steelmaking; other energy sources.	Deepsea Ventures (service contractor) has focused on a "towed dredgehead with rake" hydraulic recovery and "reduction and hydrochloric acid leach" process.	Successful prototype tests. Most active through 1982. Now curtailing sharply (>60% staff cut in past year). Mining vessel scrapped, exploration ship layed-up. Filed for NOAA licenses of 156,000 km^2.
	(Union Mines, Union Miniere S.A.), Société Générale de Belgique	Belgium	$ 5.5				
	Sun Company Inc.	U.S.	$ 50.0				
	Ente Nazionale Idrocarburi (ENI)	Italy	$162.0				
1975				$45-50			
	Inco Ltd.	Canada	$ 30.9		Minerals production and metals trading (especially nickel and others); contract offshore drilling and support operations; steelmaking; construction machinery; banking; engineering; general trading; wire rope manufacturing.	Inco, West German, and Japanese companies have focused on towed sledge hydraulic recovery; Inco has focused on a "smelting and sulfuric acid leach" metallurgical process.	Completed planned feasibility study. Proved recovery technology, 1978. Curtailed work since 1979. Inco, SEDCO inactive. Filed for NOAA license of 135,000 km^2. AHR filed separately in F.R.G.
	SEDCO, Inc.	U.S.	$ 12.4				
	Metallgesellschaft A.G.	F.R.G.					
) (25%)	Preussag A.G.	F.R.G.	$ 31.6 (c)				
	Salzgitter A.G.	F.R.G.					
	23 Companies led by Sumitomo	Japan	(b)				
				$120			
	(Amoco Minerals), Standard Oil	U.S.	$150.0		Missiles; space; electronics; aircraft manufacturing; petroleum production and trading; refined petroleum products; offshore dredging; pipelines.	Lockheed has patented a "remote-controlled, bottom-crawling" hydraulic recovery system; a "high temperature, sulfuric acid leach" metallurgical process has been examined.	Billiton withdrawing. Boa Kalis inactive. Recovery system failed to deliver nodules in at-sea test, 1978-79. Filed for NOAA license of 166,000 km^2. Lockheed now promoting R&D for other marine minerals.
	Lockheed Corporation	U.S.	$100.0				
	Lockheed Corporation	U.S.					
ils Inc.	Royal Dutch/Shell	Netherlands	$568.8				
	Royal Boskalis Westminster	Netherlands	$ 4.0				
				$83			
40) (*70%)	French Government (d)	France	$ 62.7		Oceanography; nuclear power; metallurgy; minerals production and metals trading; (especially nickel and cobalt); shipbuilding.	AFERNOD has spread its focus: CLB, towed-sledge hydraulic, and the remote-controlled autonomous shuttlecraft (PLA).	AFERNOD inactive except in area claims. Filed under French law for exploration area. R&D on PLA continues through GEMONOD, a new public group composed of CEA & CNEXO.
	French Government	France	N.A.				
	IMETAL, Elf Aquitaine	France	$ 3.3 (SLN)				
	Schneider S.A.	France	$132.2 (1982)				
formed September 1982				$42 (e)			
		Japan	$ 61.8 (1982) (b)		General trading; steelmaking; shipbuilding; transportation; ferrous and nonferrous metallurgy; industrial machinery; chemicals; metals trading; cable manufacturing; pump manufacturing.	DORD companies focused earlier on Masuda's CLB. Most recently under MITI's large-scale project, they have been developing a towed sledge, hydraulic recovery system. Metallurgical process unknown.	Most active group. Has filed for area under Japanese law. R&D through MITI/AIST "large scale project." Projected 1982-90 budget approximately $80-90 million. KODK and OMI Japanese members included.

NODULES (AFERNOD): formed 1974

water

spent, not constant dollars (Ocean Industry, 1983); U.S. Congress, 1981).

dustry (MITI) has made loans to Japanese companies participating in the multinational seabed mining .25 million was loaned by MITI. MITI's affiliate Agency of Industrial Science and Technology (AIST) covery system as a "large scale project." AIST's total 1982 Large Scale Project Budget e Parent's Annual R&D column for DORD.

's Federal Ministry of Research and Technology (Bundesministerium für Forschung und Technologie or ies since 1975.

ench fisheries agency, ISTPM, to form a new agency called: Institute Francaise de la Recherche et

ing Agency of Japan (MHAJ) in 1976-81 (GAO, 1983).

PATENT CONCENTRATION (US & Foreign Pats.)

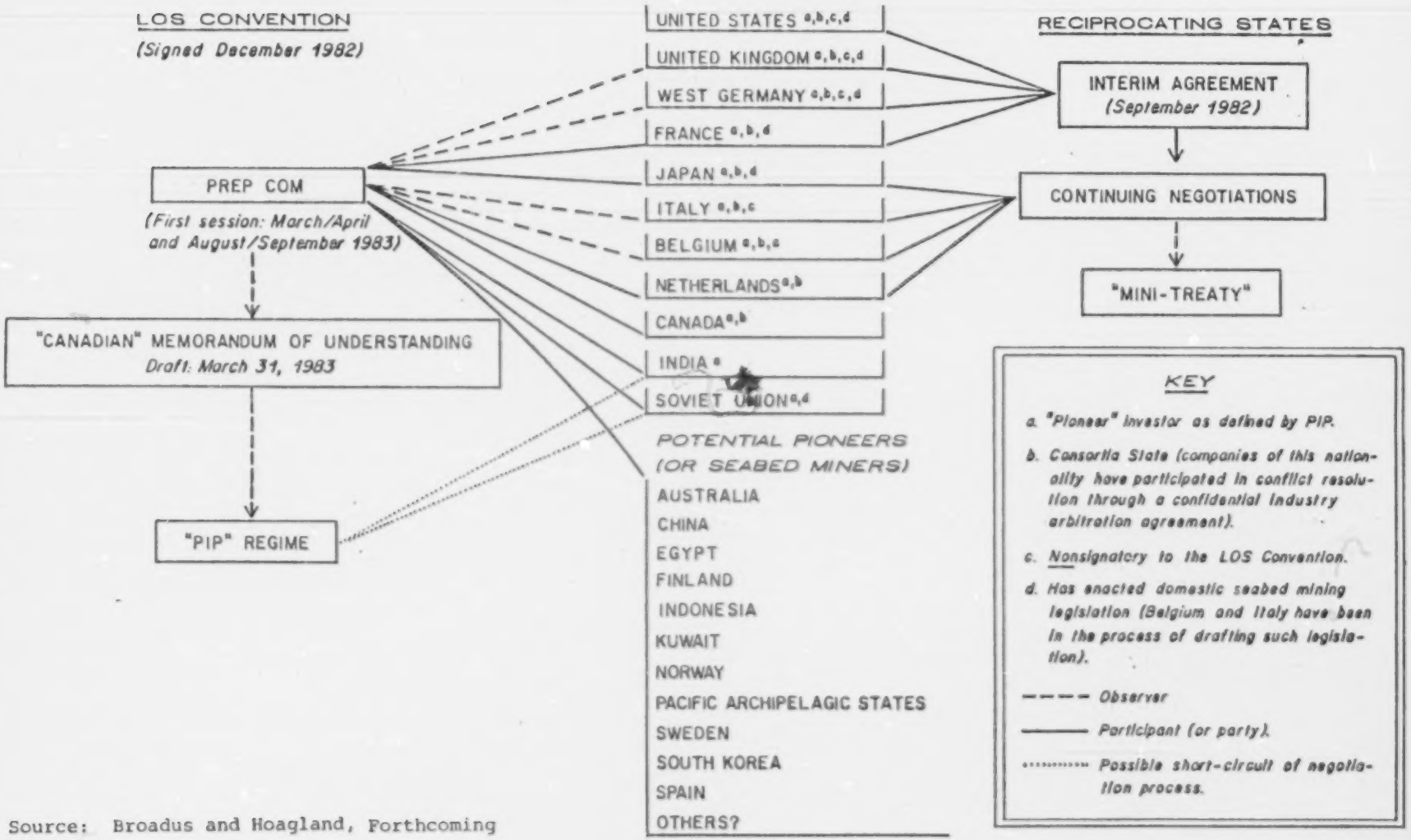
Exhibit 4

	# RECOVERY PATENTS	% OF TOTAL RECOVERY PATENTS	PROCESSING PATENTS	% OF TOTAL PROCESSING PATENTS	NUMBER OF PATENTS	% OF TOTAL PATENTS	COMMENTS (All US pats. except:)
OMA	22	15%	40	27%	62	21%	FRG: 5; CA: 4; GB: 1
OMI	19	13%	16	11%	35	12%	FRG: 7; CA: 2; GB: 1
KCON	4	3%	48	33%	52	18% (51%)	FRG: 8; CA: 6; GB: 1; SA: 1
OMCO	4	3%	3	2%	7	2%	FRG: 1
AFERNOD	12	8%	5[c]	3%	17	6%	FRG: 4; Fr: 1
DoRD	6	4%	7	5%	13	4%	JA: 4; FRG: 2; GB: 1
SOVIET UNION	10	7%	0[b]	0%	10	3%	SU: 9; FRG: 1
TOTAL CONSORTIA[a]	77	54%	119	81%	196	67%	(SEE ABOVE)
TOTAL POT. ENTRANTS	30	21%	13	9%	43	15%	FRG: 9; NL: 2; GB: 1; CA: 1
TOTAL ENGINEERING FIRMS & ENGINEERS	36	25%	15[c]	10%	51	18%	FRG: 8; Fr: 3; GB: 1
TOTALS	143	100%	147	100%	290	100%	

[a] Includes Russians.
[b] no patents have been discovered.
[c] SOFREM patents.

Exhibit 5

PARTICIPATION OF SEABED MINING STATES IN CONFLICT RESOLUTION

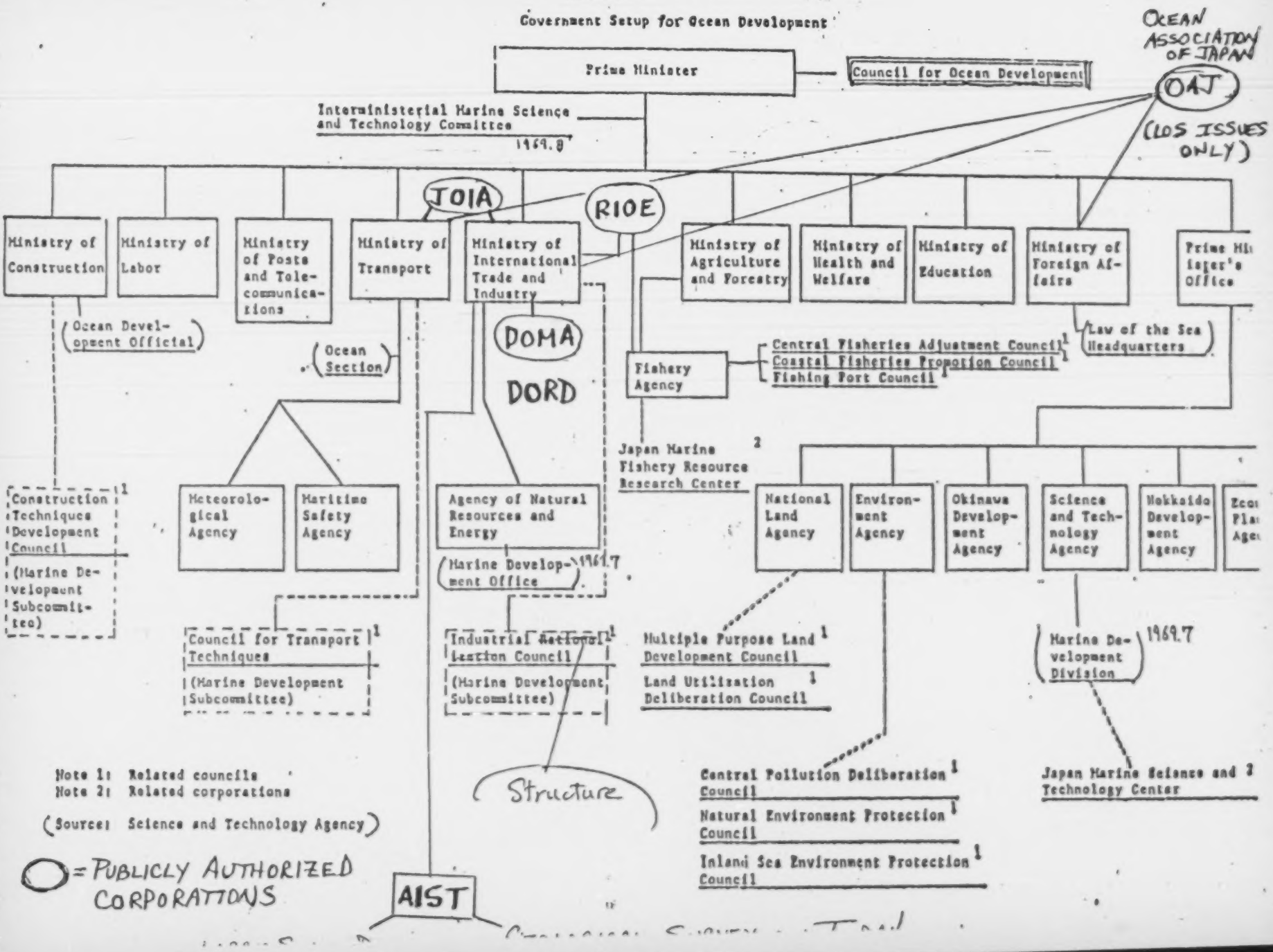


Source: Broadus and Hoagland, Forthcoming

34

Exhibit 6

Government Setup for Ocean Development



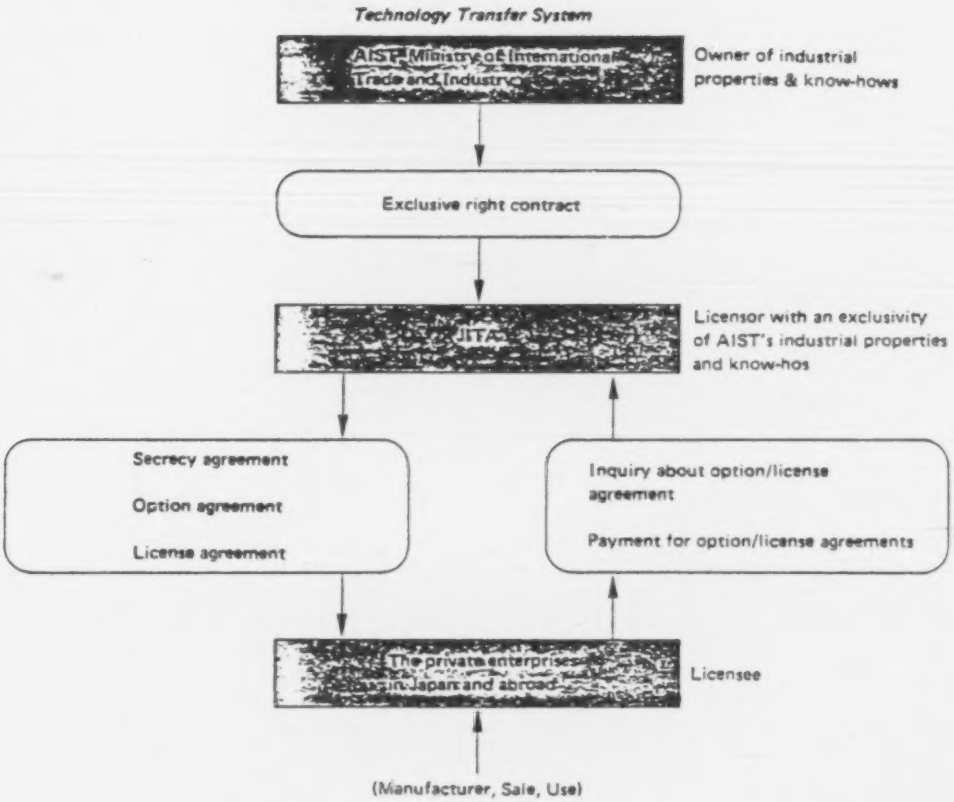
Note 1: Related councils
Note 2: Related corporations

(Source: Science and Technology Agency)

○ = PUBLICLY AUTHORIZED CORPORATIONS

Exhibit 7

TRANSFER OF NATIONAL TECHNOLOGIES DEVELOPED UNDER THE LARGE-SCALE PROJECT



Source: AIST, 1982

Exhibit 8

ONGOING NATIONAL RESEARCH AND DEVELOPMENT PROJECTS (LARGE-SCALE PROJECTS)

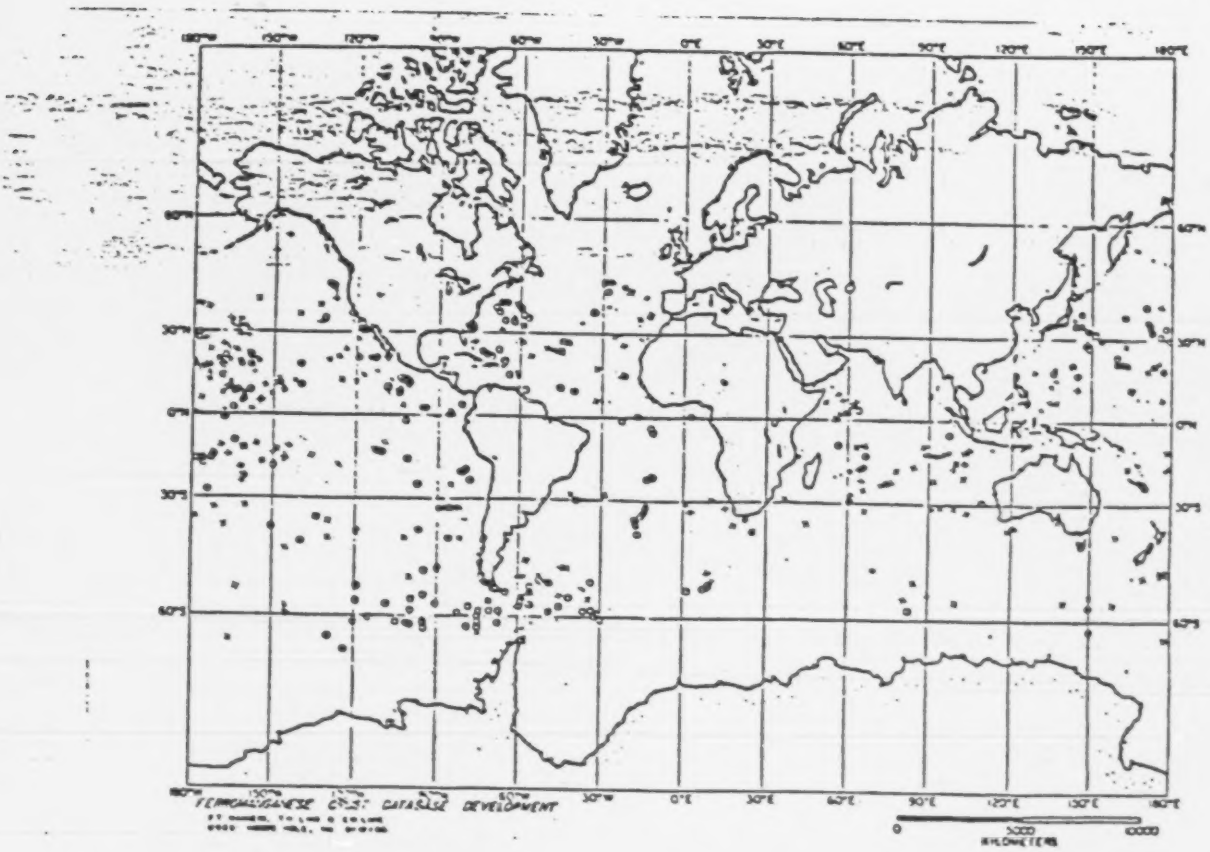
(Unit: million yen) *

Project name	R&D Period (FY)	Total R&D Expenditure	Budget for FY 1982
Resource recovery technology	1976 – 1982 (2nd phase)	about 11,300	733
	1973 – 1975 (1st phase)	about 1,300	–
Flexible manufacturing system complex provided with laser	1977 – 1983	about 13,000	3,533
Optical measurement and control system	1979 – 1986	about 18,000	3,238
C_1 chemical technology	1980 – 1987	about 15,000	2,527
Managanese nodule mining system	1981 – 1989	about 20,000	882
High speed computer system for scientific and technological uses	1981 – 1989	about 23,000	813
Automated sewing system	1982 –	–	30
Subsea oil production system	1978 – 1984	about 15,000	4,094

*(August 1982 exchange: ¥ = $0.0039).

Source: AIST, 1982

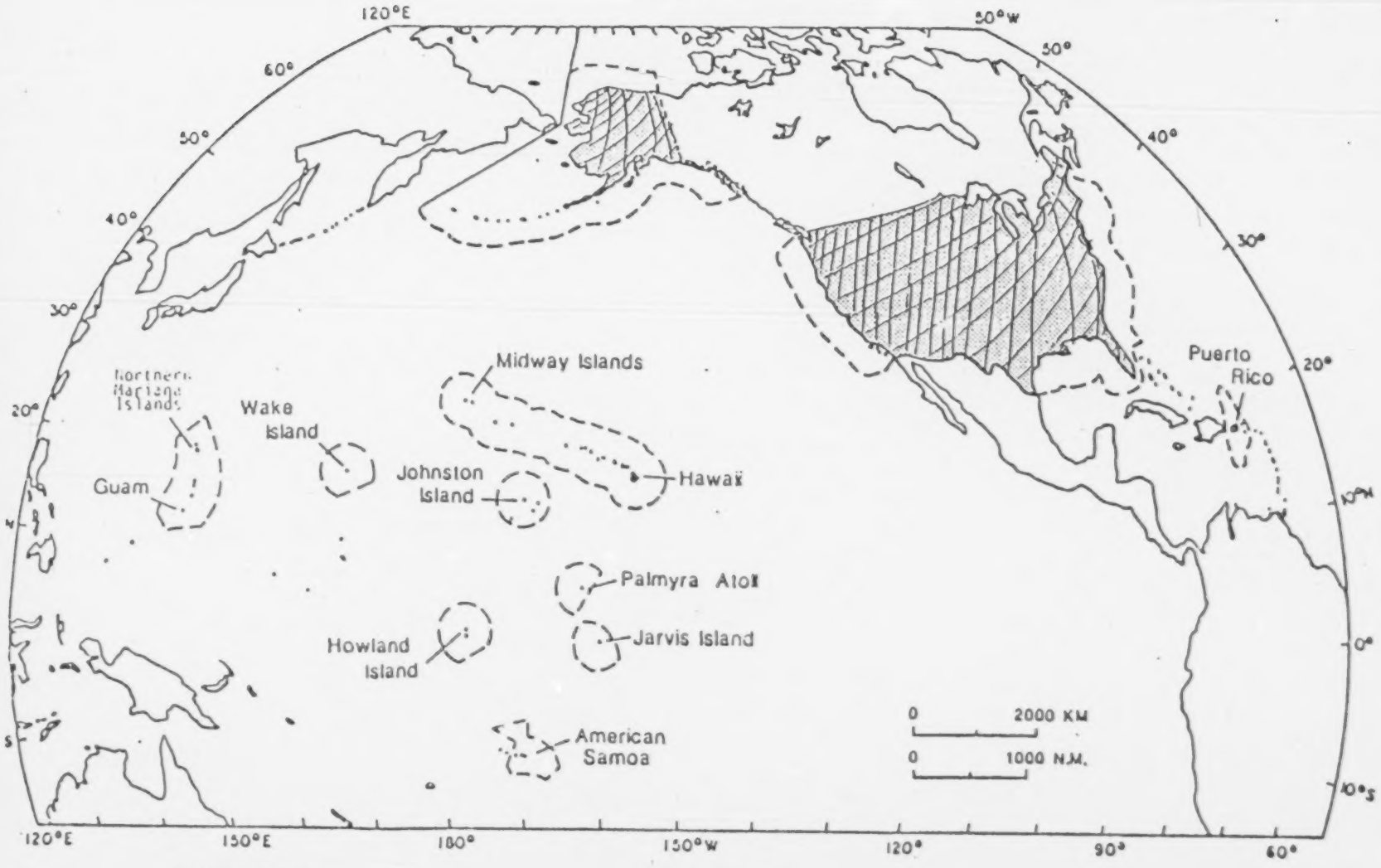
Exhibit 9



Locations where ferromanganese crust samples have been collected; data on these samples will be entered in the new data base. X marks sites of samples for which analyses have come from the Scripps Institution manganese nodule data base[7]; O marks sites of newly collected specimens.

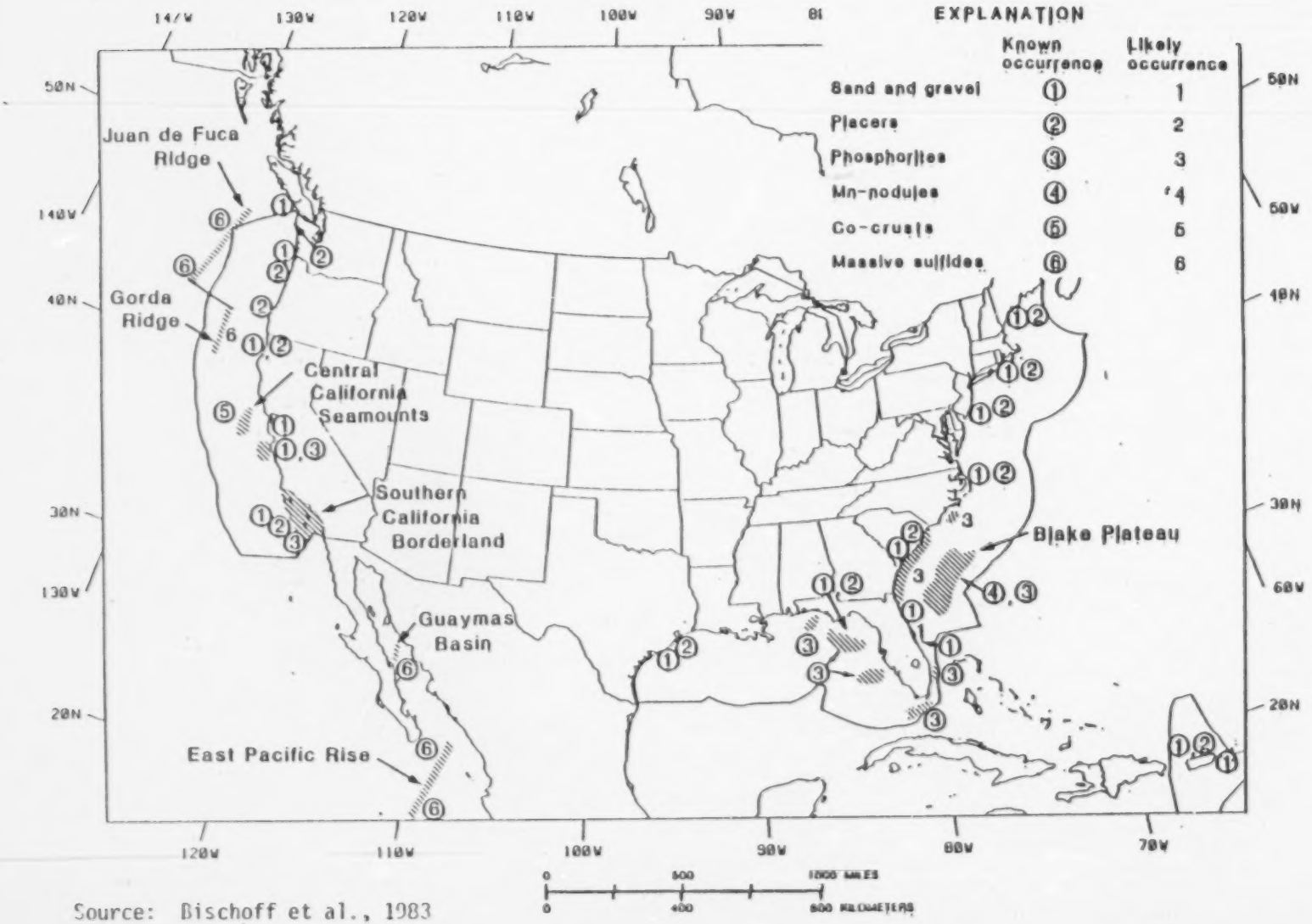
Source: Manheim, Ling, and Lane, 1983

Exhibit 10



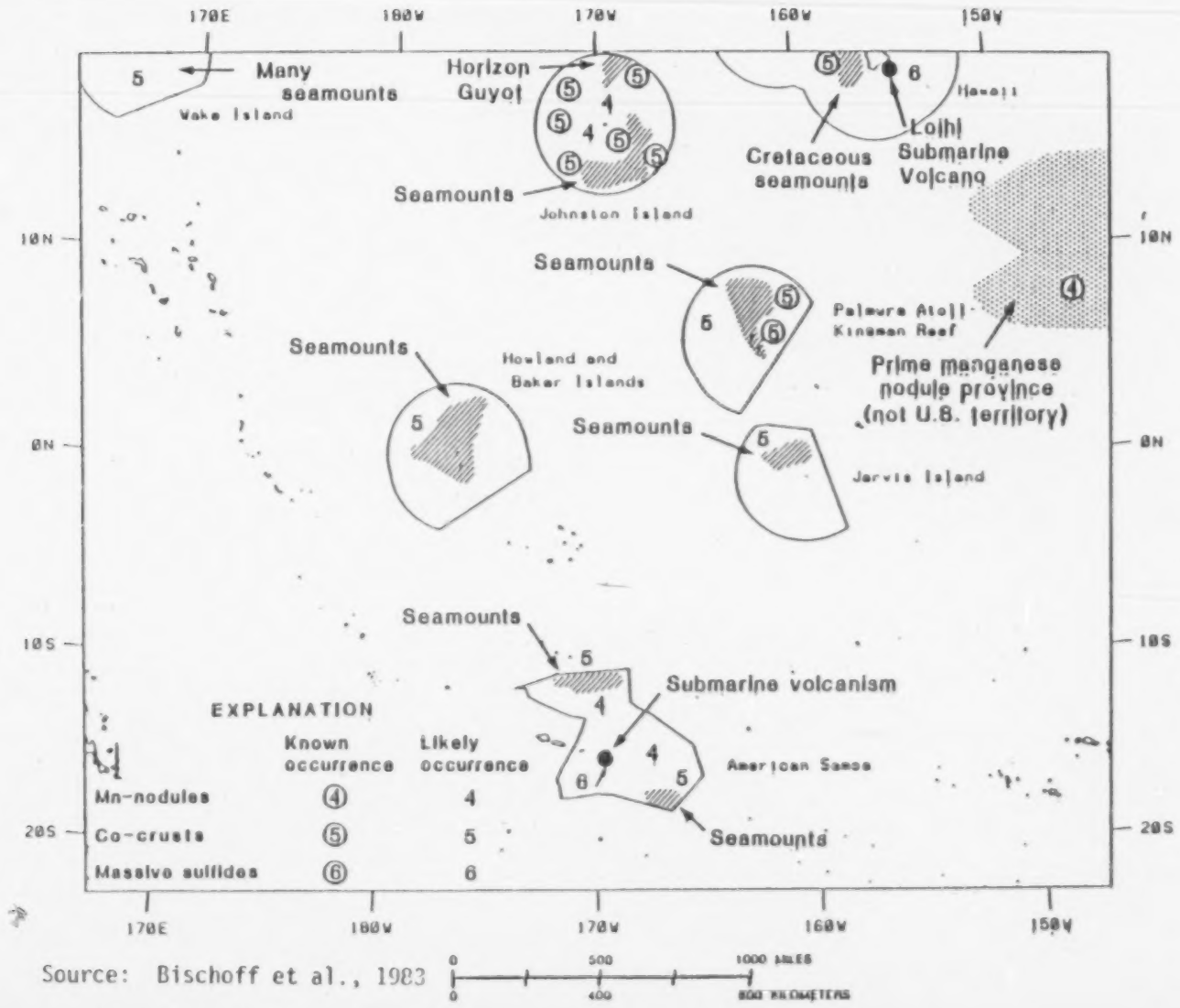
Sketch map showing approximate outlines of Exclusive Economic Zone of the United States, Commonwealth of Puerto Rico, Commonwealth of the Northern Mariana Islands and United States overseas possessions. (Based on map published by U.S. Geological Survey, Department of the Interior, to show compilation of subsea energy and mineral resources (MF-1260) but not drawn to determine legal boundaries.) Source: Rischoff et al 1983

Exhibit 11



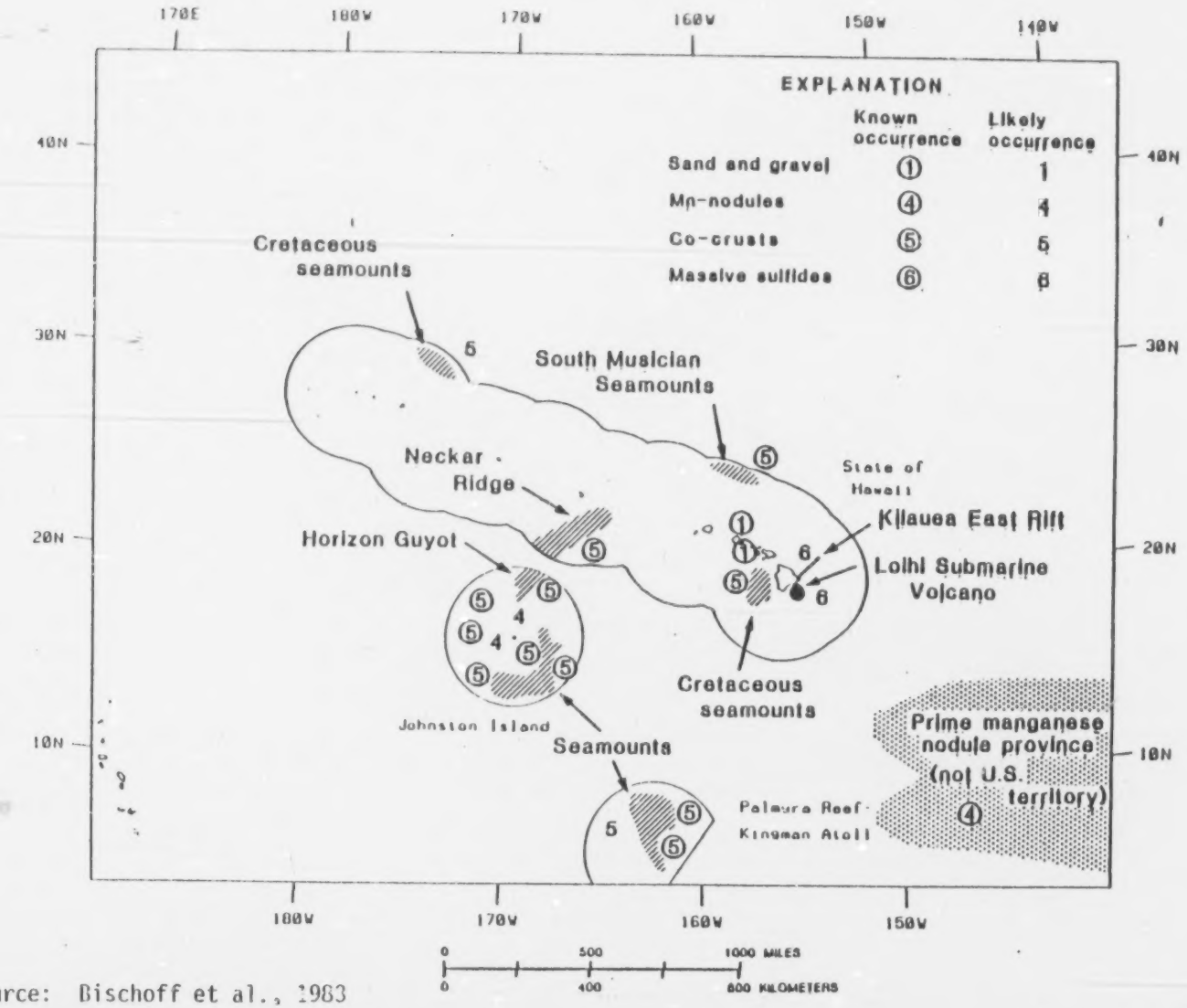
Source: Bischoff et al., 1983

Exhibit 12



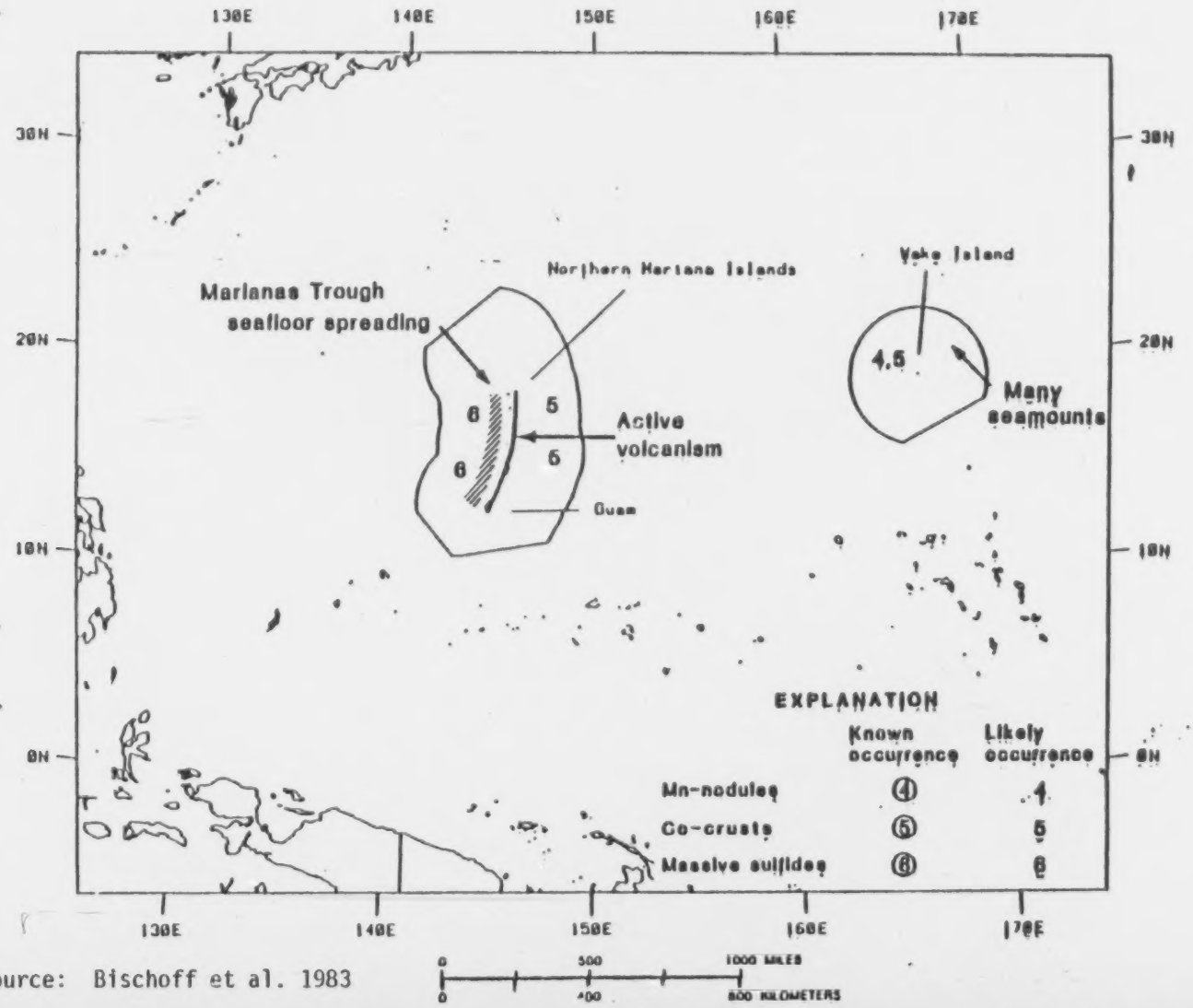
Source: Bischoff et al., 1983

Exhibit 13



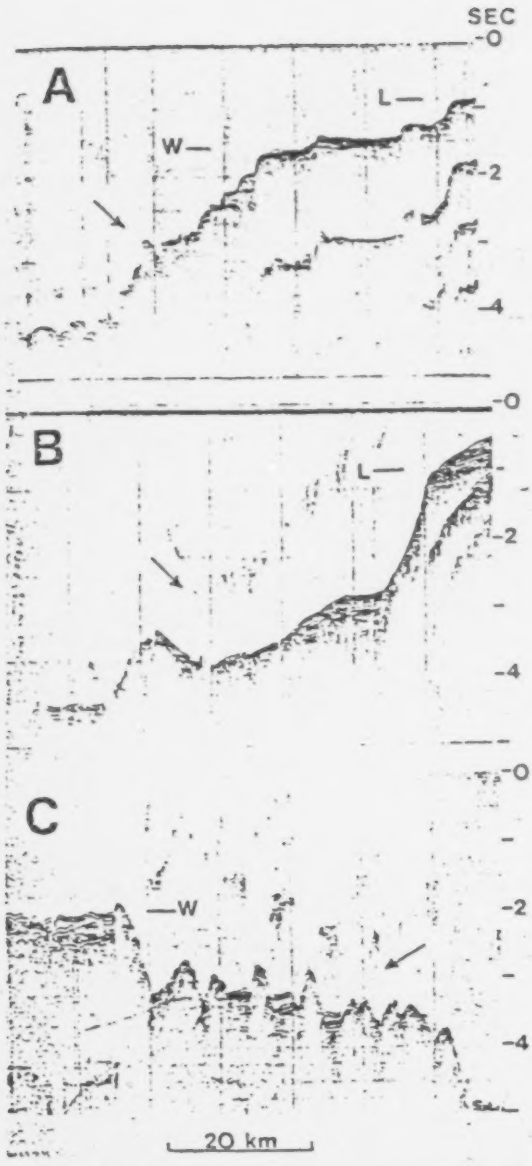
Source: Bischoff et al., 1983

Exhibit 14



Source: Bischoff et al. 1983

Exhibit 15

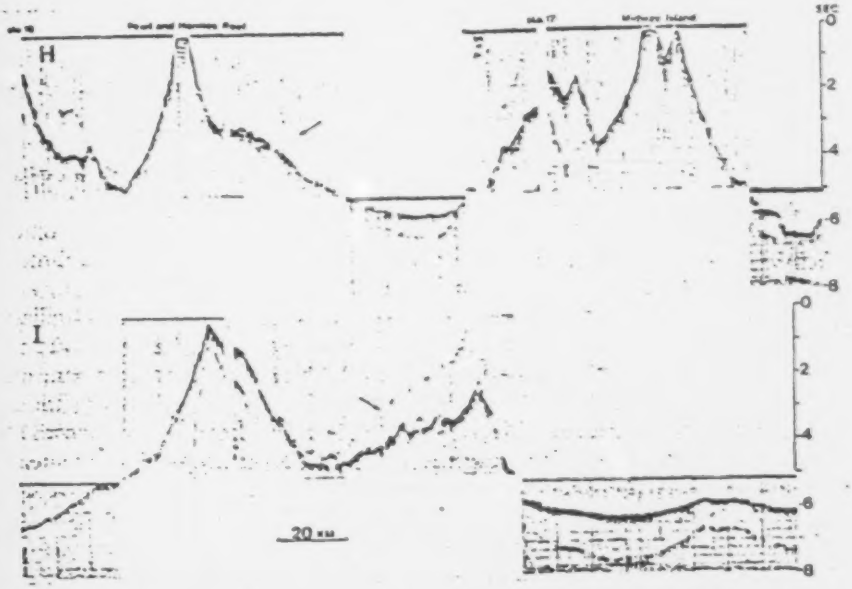


Seismic reflection profiles comparing slope relief on islands of various ages in the Hawaiian Chain. A. Northwestern side of Hawaii. B. Northwestern side of Oahu. C. North western side of Gardner Pinnacles. Letters indicate the Lualualei (*L*) and Waho (*W*) terrace levels. Depths given in two-way travel time can be converted to meters assuming a sound velocity of 1500 m/sec in seawater; that is, the Lualualei terrace level (370—560 m; Table I is situated at approximately 0.5—0.75 sec. The Waho terrace level (900—1200 m; Table I is situated at 1.20—1.60 sec. Arrows indicate the block-faulted slope below the Waho level

Source: Craig, Andrews, and Meylan, 1982

Exhibit 16

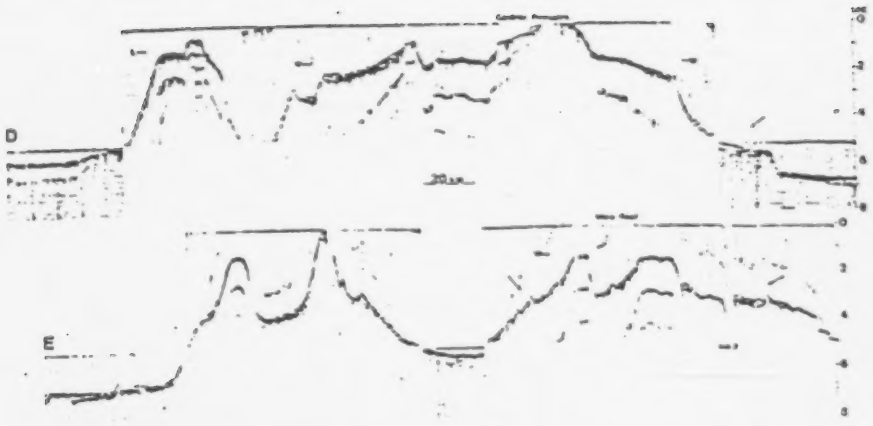
Reflection profiles in the Gardner Pinnacles area. Note the distinctly block-faulted character of this feature. Symbols are described in Fig.2 caption.



Reflection profiles in the Midway Island area. These are typical of seamount settings. Deep terrace levels are not developed, but minor escarpments on block-faulted slopes are similar to slopes in the southeastern Hawaiian Archipelago. Symbols are described in ~~Fig.2 caption.~~ Exhibit 15 .

Source: Craig, Andrews, and Meylan, 1982

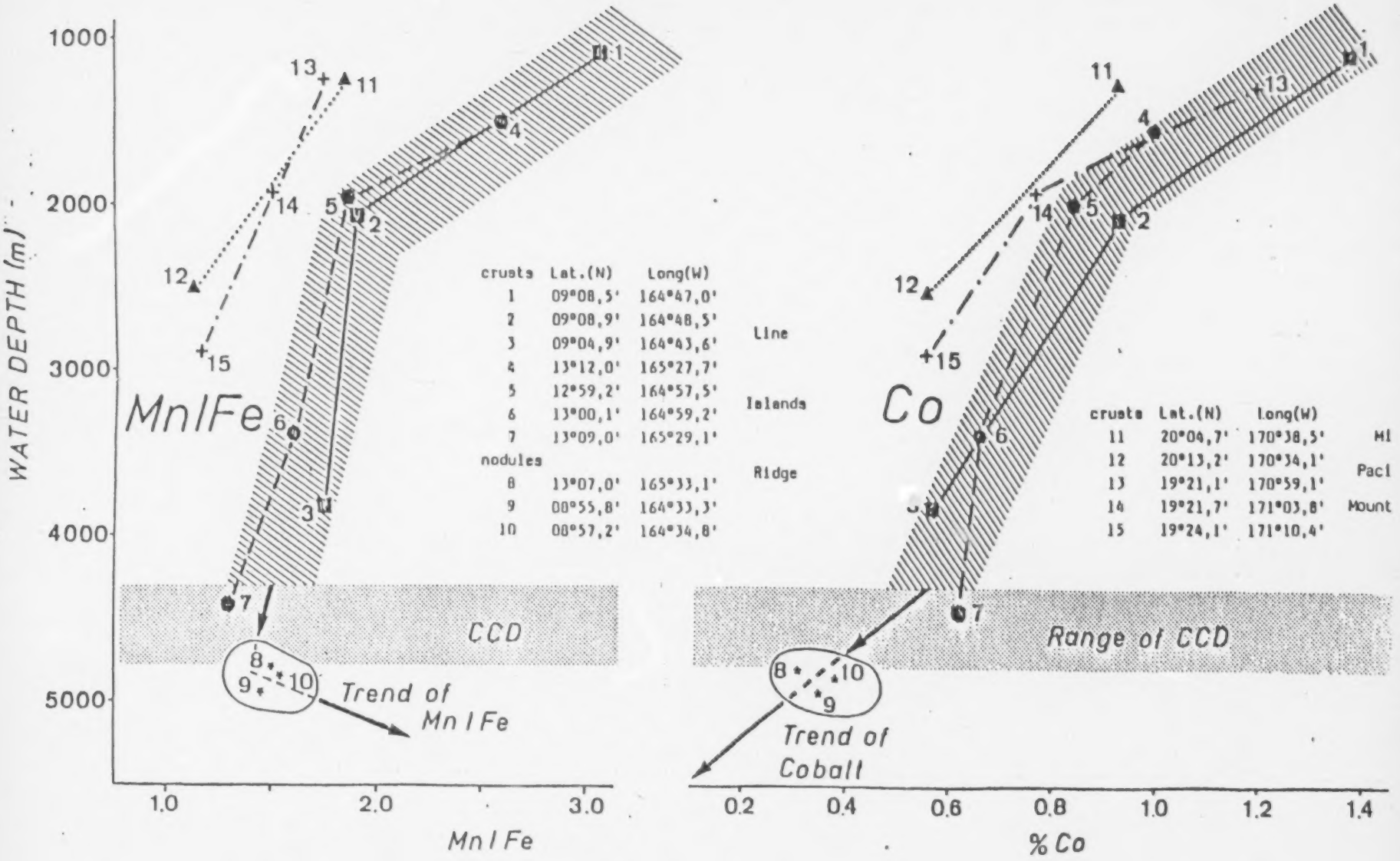
Exhibit 17



Reflection profiles in the central portion of the Hawaiian Ridge at Gardner Pinnacles and Maro Reef. Figure symbols are described in ~~Fig. 2 caption.~~ Exhibit 15 .

Source: Craig, Andrews, and Meylan, 1982

Exhibit 18

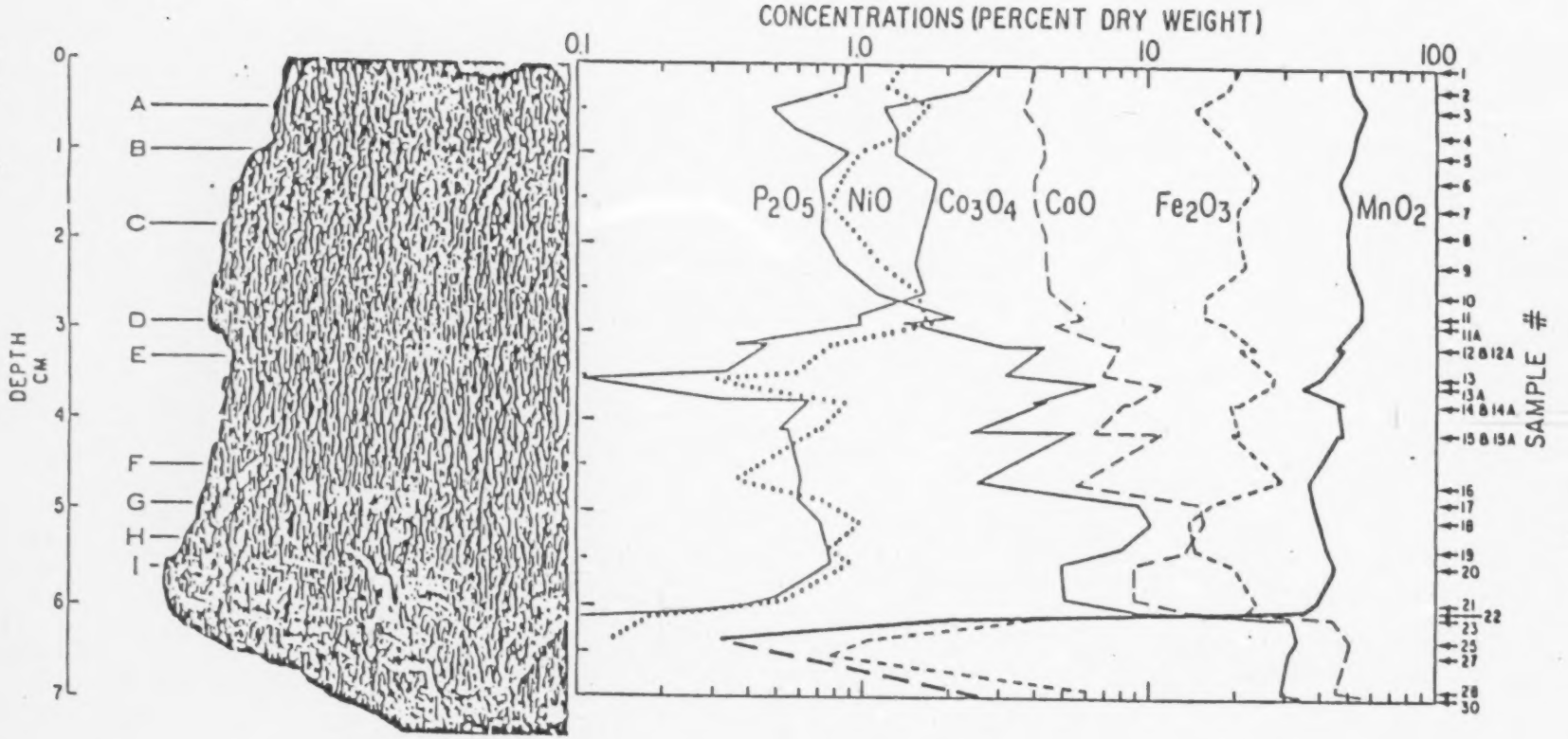


crusts	Lat.(N)	Long(W)	
1	09°08,5'	164°47,0'	Line
2	09°08,9'	164°48,5'	
3	09°04,9'	164°43,6'	
4	13°12,0'	165°27,7'	
5	12°59,2'	164°57,5'	Islands
6	13°00,1'	164°59,2'	
7	13°09,0'	165°29,1'	
nodules			
8	13°07,0'	165°33,1'	Ridge
9	08°55,8'	164°33,3'	
10	08°57,2'	164°34,8'	

crusts	Lat.(N)	Long(W)	
11	20°04,7'	170°38,5'	MI
12	20°13,2'	170°34,1'	Pacl
13	19°21,1'	170°59,1'	
14	19°21,7'	171°03,8'	Mount
15	19°24,1'	171°10,4'	

Source: Halbach and Manheim, 1983

Exhibit 19



Source: Halbach and Manheim, 1983

Exhibit 20

Mean composition of all seamount oxide samples in weight percent of dry matter (110^0C) with standard deviations (n=26 to 46).

Mn	24.6 ± 4.0	Co	.79 ± .33
Fe	14.5 ± 2.5	Ni	.49 ± .20
Ti	.96 ± .20	Cu	.065 ± .39
Ca	4.24 ± 3.17	Zn	.072 ± .018
P	1.24 ± 1.5		

Source: Halbach and Manheim, 1983

Exhibit 21

Comparison of Metal Grades

in Manganese Crusts and Nodules

(percent)

	Crusts[a]	Nodules[b]
Cobalt	0.90	0.27
Nickel	0.50	0.76
Copper	0.06	0.54
Manganese	24.7	20.1

[a]Average of 57 samples from depths of less than 2,400 m from the Exclusive Economic Zones of the Hawaiian Archipelago, Johnston and Palmyra Islands (Craig et al. 1982; Halbach 1981).

[b]Average of over 1700 stations from the Pacific Ocean (McKelvey et al. 1983).

Source: Clark, Johnson, and Chinn, 1983

Exhibit 22

Average Metal Grades in
Crust Samples From the Hawaiian
Archipelago and Johnston-Palmyra Region
(percent)

	Hawaiian Archipelago[a]		Johnston-Palmyra Region[b]		Weighted Average for Study Area
	Average	Range	Average	Range	
Cobalt	0.88	0.41-1.64	0.92	0.48-1.92	0.90
Nickel	0.48	0.25-1.11	0.51	0.22-0.82	0.50
Copper	0.05	0.03-0.12	0.06	0.02-0.18	0.06
Manganese	23.6	17.0-33.0	25.7	18.4-33.2	24.7

[a]Crusts between 0.5 cm and 7.0 cm thickness were used in this assessment to reduce possible substrate dilution effects (n = 27 out of 47) (Craig et al. 1982).

[b]Average of 30 samples from depths between 2400 m and 800 m in the Johnston-Palmyra region (Halbach 1981).

Source: Clark, Johnson, and Chinn, 1983

Exhibit 23

Metal Grades and Values for Hypothetical Prime Mine Sites

Metal	Manganese Crusts				Manganese Nodules			
	Percent[a]	Lbs/ metric ton	$/metric ton[b] 1972$	1982$	Percent[a]	Lbs/ metric ton	$/metric ton[b] 1972$	1982$
Cobalt	1.0	22.05	50.72	165.38	0.2	4.41	10.14	33.08
Nickel	0.5	11.02	15.43	37.47	1.4	30.86	43.20	104.92
Copper	0.06	1.32	0.66	1.32	1.2	24.46	13.23	26.46
Manganese	24.7	544.5	16.34	43.57	28	617.29	18.52	49.38
Total			83.15	247.74			85.09	213.84

[a]Prime mine sites will have higher metal grades than average for a region. Because of the limited sampling, conservative grades were used for crusts with an increase only in cobalt grade from the Study Area average of 0.9 percent to 1.0 percent. The grades for nodules are from Arthur D. Little, Inc. (1979).

[b]An attempt was made to avoid high and low prices and to present prices that might be used within a planning group within a major mining company. In the early 1970s companies were using prices similar to the 1972 $ column; likewise in the early 1980s companies are assuming prices similar to the 1982 $ column. Prices per pound for 1972 are Co $2.30, Ni $1.40, Cu $0.50 and Mn $0.03; and for 1982 are Co $7.50, Ni $3.40, Cu $1.00 and Mn $0.08.

Source: Clark, Johnson, and Chinn, 1983

Exhibit 24

Comparative metal concentrations and values for seamount crusts and abyssal nodules. MPM refers to crusts from the Mid Pacific Mountains - Line Islands trend, at water depths of 2600 m or less. MIDPAC refers to samples from all depths encompassed in the MIDPAC 81 cruise(n =61). CC refers to prime abyssal manganese nodules from the Clarion-Clipperton area (Frazer and Fisk, 1980). Oxide concentrations are 16 kg/m^2 for the crusts(see text) and 8 kg/m^2 for the prime abyssal nodules(halbach and Feller, 1980). Molybdenum metal values for the nodule concentrations are taken from previous studies(Cronan, 1980). Metal prices are for September 1983(source: U.S. Bureau of Mines commodity specialists). Decimals are for computation only. Totals are rounded to nearest 2%.

		AREA											
Compo-	Price	MPM crusts			Line Is. crusts			MIDPAC crusts			Nodules(CC)		
nent	$/kg	%	$/tonne	$/$m^2$	%	$/tonne	$/$m^2$	%	$/tonne	$/$m^2$	%	$/tonne	$/$m^2$
Mn*	.33	25.0	82.50	1.32	25.0	82.50	1.32	24.6	81.18	1.29	25.2	83.16	.67
Mn**	1.50	25.0	375.00	6.00	25.0	375.00	6.00	20.6	369.00	5.90	25.2	370.00	3.02
Co	12.65	.83	105.00	1.68	1.00	126.50	2.02	..79	99.93	1.60	.24	30.36	.24
Ni	7.02	.34	23.86	.38	.55	38.61	.62	.49	34.39	.55	1.21	84.94	.68
Cu	1.54	.07	1.08	.02	.07	1.08	.02	.065	1.00	.02	1.00	15.40	.12
Mo	8.91	.06	5.34	.09	.064	5.70	.09	.06	5.35	.09	.04	3.56	.03
Total value of last four components plus Mn*		220		3.50		255	4.10		220	3.55		220	1.75
Total value of last four components plus Mn**		510		8.17		550	8.75		510	8.10		505	4.10

* Ferromanganese(78% Mn) not recalculated to 100% Mn basis

** Manganese(99%)

Source: Halbach and Manheim, 1983

Exhibit 25

INFORMATION REQUIREMENTS

A. PRESENT AND PROSPECTIVE DEMAND CONDITIONS

- USES
- INDICATIVE FACTORS
- TREND
- SUBSTITUTES

B. CHARACTERISTICS OF DEPOSITS

- GRADE-TONNAGE DISTRIBUTION
- PHYSICAL-CHEMICAL PROPERTIES
- LOCATION
- DIMENSIONS
- OVERBURDEN
- GEOLOGICAL & HYDROLOGICAL SETTING

C. LONG-RUN SUPPLY CONDITIONS

- PRICE-QUANTITY PROJECTIONS
- SUPPLY PROSPECTS WITHOUT
- CRITERIA FOR COMMERCIAL QUALITY
- COST TRENDS
- CONJECTURAL TECHNIQUES & RECOVERY COSTS